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Rapid field assessments of impacts of plant fungal pathogen *Austropuccinia psidii* on five high priority Myrtaceae species in New South Wales, Australia

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Abstract: In 2010, the plant fungal pathogen *Austropuccinia psidii* was detected in Australia. It has since spread rapidly through the eastern states of Australia causing significant population declines in a number of susceptible species. However, there are still a number of potentially vulnerable species that lack the necessary field observations that are needed to accurately gauge the risk *Austropuccinia psidii* poses to them. Because of this, rapid field assessments of these species have been given the utmost priority. In the spring of 2018 (October) we carried out rapid field assessments for five high priority species. We did not observe active *Austropuccinia psidii* infection on any of the species at the time of assessment despite the majority of individuals having susceptible new flush. However, we did find evidence of significant previous infection (branch dieback) in the largest *Archirhodomyrtus beckleri* population we assessed. Therefore, to confirm our observations, it is necessary to re-assess this population when environmental conditions are more favourable for infection to occur in order.

Keyword: dieback; infection; Myrtle Rust; plant fungal pathogen; susceptibility

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Introduction and Methods

In 2010 the plant fungal pathogen *Austropuccinia psidii* (commonly known as Myrtle Rust), which is native to South and Central America (Winter, 1884; Granados et al., 2017), was detected in Australia (Carnegie et al., 2010). It has since spread rapidly through the eastern states (New South Wales (NSW), Queensland and Victoria) of mainland Australia as well as to Tasmania and the Northern Territory (Carnegie & Pegg, 2018). It infects the young growing tissue of Myrtaceae species resulting in leaf distortion, defoliation, branch dieback and even mortality in highly susceptible species after multiple re-infection events (Carnegie et al., 2016; Pegg et al., 2017). Despite its short residency time, *Austropuccinia psidii* has already caused dramatic declines in a number of highly susceptible species. For example, Pegg et al. (2017) reported significant population declines in wet sclerophyll forest species *Archirhodomyrtus beckleri*, *Decaspermum humile*, *Gossia hillii* and *Rhodamnia maideniana* in south-east Queensland while Carnegie et al. (2016) reported similar declines in rainforest mid-storey species *Rhodamnia rubescens* and *Rhodomyrtus psidioides* in NSW.

Recently, all the available information regarding the impacts of *Austropuccinia psidii* on native Australian Myrtaceae species was collated in extensive report entitled 'Myrtle Rust reviewed' (Makinson, 2018) and 45 species potentially most at risk of *Austropuccinia psidii* impacts in Australia were identified. However, the necessary field observations that are needed to accurately gauge the risk *Austropuccinia psidii* poses to these species in the natural environment are currently lacking and the report recommended that rapid field assessments of these species should be given the utmost priority.

In the spring of 2018 (3rd-14th of October) we carried out rapid field assessments for five of these species: *Archirhodomyrtus beckleri* (F.Muell.) A.J.Scott, *Austromyrtus dulcis* (C.T.White) L.S.Sm., *Gossia fragrantissima* (F.Muell. ex Benth.) N.Snow & Guymer, *Syzygium hodgkinsoniae* (F.Muell.) L.A.S.Johnson and *Syzygium oleosum* (F.Muell.) B.Hyland (Table 1). We targeted NSW populations of these species as there is a general lack of field observations in this region of their distribution. In south-east Queensland, *Austropuccinia psidii* has been shown to have varying impacts on these species. For *Archirhodomyrtus beckleri,* and to a lesser extent for *Syzygium hodgkinsoniae* (juvenile plants only), *Austropuccinia psidii* has been reported to have caused significant dieback, while for the other three species little or no impact has been observed (Pegg et al., 2017; Makinson, 2018).

Table 1: Growth form and habitat of the five species assessed (from PlantNET www.plantnet.rbgsyd.nsw.gov.au) and locations of populations that were assessed for each species.

Species	Growth form	Habitat	Population	Stand	Location lat/long
Archirhodomyrtus beckleri	Shrub/tree	Rainforest and wet sclerophyll forest	Knorrit SF	1	S 31.7826 E 152.1298
				2	S 31.7868 E 152.1270
			Kerewong	1	S 31.6354 E 152.5345
				2	S 31.6349 E 152.5451
			Coopernook SF	1	S 31.8055 E 152.6203
Austromyrtus dulcis	Semi-prostrate spreading shrub	Heath and dry sclerophyll forest	Pottsville	1	S 28.3913 E 153.5609
				2	S 28.3737 E 153.5709
			Byron Bay	1	S 28.6647 E 153.6151
				2	S 28.6560 E 153.6219
			Bundjalung NP	1	S 29.3636 E 153.2885
				2	S 29.3581 E 153.3441
			Broadwater NP	1	S 29.0393 E 153.3944
				2	S 29.0138 E 153.4610
Gossia fragrantissima	Shrub/tree	Rainforest	Georgica	1	S 28.9773 E 153.2916
			Coraki	1	S 28.6542 E 153.1490
			Boatharbour	1	S 28.7788 E 153.3333
			Main Arm	1	S 28.5194 E 153.4225
				2	S 28.5270 E 153.4268
Syzygium hodgkinsoniae	Tree	Rainforest	Nemarotu	1	S 28.5606 E 153.4035
				2	S 28.5678 E 153.3860
			Lindendale	1	S 28.8131 E 153.3821
			Nightcap NP	1	S 28.6361 E 153.3362
Syzygium oleosum	Tree	Rainforest	Byron Bay	1	S 28.6417 E 153.6293
				2	S 28.6377 E 153.6309
			Bongil Bongil NP	1	S 30.4407 E 153.0626
				2	S 30.4331 E 153.0727
			Bundjalung NP	1	S 29.3581 E 153.3440
			Strickland SF	1	S 33.3786 E 151.3238

For our rapid field assessments, we used the NSW Office of Environment and Heritage repository of biodiversity data (BioNET, www.bionet.nsw.gov.au) to select 3-4 populations per species, which were spaced across a large proportion of the species distributions in NSW. Selected populations within a species were separated by a minimum of 30 km. When possible, we assessed two stands within each population, with each stand consisting of 10 individuals of varying heights. Individuals ≤1 m in height were classified as seedlings, while individuals >1 m in height were classified as mature plants. This classification was not used for *Austromyrtus dulcis* as the majority of individuals were ≤1 m in height despite being mature plants. Stands were separated by a minimum of 500 m and a maximum of 3 km. At the individual-level, we recorded presence/absence of flower production, fruit production, susceptible new growth flush and active *Austropuccinia psidii* infection, as well as the extent of branch dieback. At the stand-level, we recorded if recruitment was occurring (i.e. if seedlings were present). It should be noted that it was extremely difficult to distinguish signs of previous *Austropuccinia psidii* infection on leaves from other factors that cause leaf damage (e.g. heat stress, attack by other natural enemies) so we do not comment on it in this communication.

Results and Discussion

We did not observe active *Austropuccinia psidii* infection on the leaves of any of the species assessed, despite the majority of individuals (>90%) having susceptible new growth flush. Three species were in flower (*Austromyrtus dulcis*, *Syzygium oleosum*) or fruiting (*Syzygium hodgkinsoniae* and *Syzygium oleosum*), but no active *Austropuccinia psidii* infection was observed on the reproductive structures of these species. With the exception of *Archirhodomyrtus beckleri*, all of the species had at least one population that was in close proximity to other highly susceptible species that were observed to be severely infected with *Austropuccinia psidii* at the time of assessment. We observed severely infected individuals of *Gossia hillii* (Nightcap National Park, Wardell), *Rhodamnia maideniana* (Urlip) and *Syzygium jambos* (Lismore) close to populations of the species we assessed suggesting that environmental conditions were favourable for infection to occur (15-25°C at 95% humidity). So the lack of infection observed on our study species cannot be ascribed to lack of exposure to the pathogen. We observed branch dieback in all of the five species we assessed (Table 2), but with the exception of *Archirhodomyrtus beckleri,* we attributed this to factors other than *Austropuccinia psidii* infection. These factors included senescence (*Gossia fragrantissima*, *Syzygium hodgkinsoniae*, *Syzygium oleosum*), stands being in close proximity to anthropogenic disturbances such as sugar cane farms (*Austromyrtus dulcis, Gossia fragrantissima*), natural enemy attack (*Gossia fragrantissima, Syzygium oleosum*), and/or the drought conditions that existed at the time of assessment (*Austromyrtus dulcis, Gossia fragrantissima*). Considering this, we suggest that the *Austromyrtus dulcis*, *Gossia fragrantissima*, *Syzygium hodgkinsoniae* and *Syzygium oleosum* populations we assessed are likely to be resistant or only slightly susceptible to *Austropuccinia psidii* infection. However, it should be acknowledged that south-east Queensland populations of *Austromyrtus dulcis*, *Syzygium hodgkinsoniae* and *Syzygium oleosum* have been assigned a spread of susceptibility ratings ranging from relatively tolerant to highly susceptible (Pegg et al., 2018). Therefore, the observations we made during our rapid field assessments may not necessarily be applicable to NSW populations as a whole.

For the *Archirhodomyrtus beckleri* populations we assessed (the only species we assessed south of Port Macquarie), it is likely that environmental conditions were not favourable for infection to occur; *Gossia hillii* and *Rhodamnia rubescens* individuals that occurred this far south did not have any active infection despite showing obvious signs of previous severe infection (leaf distortion, defoliation and branch dieback). Like the other four species we assessed, the Kerewong and Coopernook State Forest populations of *Archirhodomyrtus beckleri* appeared to have little to no impact from *Austropuccinia psidii*. However, the Knorrit State Forest population did show clear signs of previous *Austropuccinia psidii* infection, with obvious defoliation (compared to individuals of the same species from the other populations) and branch dieback (>30% whole dieback and >90% part dieback; see Table 2). Surprisingly, the smaller seedlings in this population did not display the same signs of previous infection as their mature counterparts, perhaps due to these seedlings germinating or developing most of their biomass since the last significant infection event in this area. Although the individuals in this population did not have any active infection, neither did co-occurring individuals of the highly susceptible *Rhodamnia rubescens*, providing strong evidence that environmental conditions were not favourable for infection at the time of assessment. Therefore, to confirm our observations, it is necessary to re-assess this population when environmental conditions are more favourable for infection to occur. Considering that this was by far the largest population of *Archirhodomyrtus beckleri* we assessed (>50 individuals), and that this species is displaying significant declines in south-east Queensland, we suggest that confirming our observations in relation to *Austropuccinia psidii* impact is critical to better inform management decisions for *Archirhodomyrtus beckleri*.

From our rapid field assessments, it is clear that *Austropuccinia psidii* was only impacting populations of *Archirhodomyrtus beckleri,* and not the populations of the other four species. For *Archirhodomyrtus beckleri*, the notable between population differences in branch dieback, suggests that certain populations may be more resistant to infection than others. Therefore, we can conclude that *Austropuccinia psidii* does not currently pose a significant extinction threat to *Archirhodomyrtus beckleri* at the overall species-level, at least in NSW. At the population-level, specifically the Knorrit State Forest population of *Archirhodomyrtus beckleri*, we suggest that *Austropuccinia psidii* does not pose an immediate threat, as the population had significant recruitment, and displayed no visible signs of whole seedling or mature tree mortality (e.g. skeletons of dead individuals). Rapid field assessments may only provide a narrow timeframe in which to observe *Austropuccinia psidii* impacts on susceptible species, but because impacts (e.g. leaf distortion, defoliation, branch dieback) are generally visible for an extended period of time, we believe it is still a useful method to gauge impacts with reasonable confidence. However, repeated monitoring efforts still represent the best strategy to accurately determine a species susceptibility to *Austropuccinia psidii* within and across populations; this is vital to identify highly resistant individuals or populations that could be utilised as genetic resources for potential recovery actions for highly susceptible populations.

Table 2: Information on branch dieback (both whole and part) and on potential for recruitment (presence/absence of flowers, fruit and seedlings) for each assessed population of each species. For the dieback data, the number of assessed individuals from each height class (seedling, mature) is given in brackets. Seedling data is not presented for *Austromyrtus dulcis* because most individuals were ≤1m (seedling class) in height despite being mature plants. Note that no individuals had active *Austropuccinia psidii* infection on their leaves, flowers or fruit at the time of assessment (October 2018) despite the majority having new growth flush. NP=National Park, SF=State Forest.

Species	Population	Stand	Presence of flowers/fruit	Presence of seedlings	Whole/part branch dieback-seedlings (%)	Whole/part branch dieback-mature (%)
Archirhodomyrtus beckleri	Knorrit SF	1	N/N	Y	38/100 (n=1)	31/100 (n=9)
		2	N/N	Y	3/9 (n=6)	34/94 (n=4)
	Kerewong	1	N/N	Y	5/80 (n=2)	4/26 (n=8)
		2	N/N	Y	9/57 (n=6)	18/88 (n=4)
	Coopernook SF	1	N/N	Y	0/16 (n=3)	6/36 (n=7)
Austromyrtus dulcis	Pottsville	1	N/N	-	-	0/4 (n=10)
		2	N/N			0/4 (n=10)
	Byron Bay	1	N/N	-	-	7/28 (n=10)
		2	N/N			5/30 (n=10)
	Bundjalung NP	1	N/N	-	-	3/6 (n=10)
		2	Y/N			11/37 (n=10)
	Broadwater NP	1	N/N	-	-	12/18 (n=10)
		2	Y/N			10/19 (n=10)
Gossia fragrantissima	Georgica	1	N/N	Y	16/92 (n=3)	16/84 (n=7)
	Coraki	1	N/N	N	NA	15/100 (n=10)
	Boatharbour	1	N/N	N	NA	18/89 (n=5)
	Main Arm	1	N/N	Y	0/0 (n=1)	21/70 (n=9)
		2	N/N	Y	8/37 (n=4)	6/43 (n=6)
Syzygium hodgkinsoniae	Nemarotu	1	N/N	N	NA	0/2 (n=10)
		2	N/Y	Y	0/0 (n=5)	16/14 (n=5)
	Lindendale	1	N/N	Y	6/0 (n=6)	0/0 (n=4)
	Nightcap NP	1	N/N	Y	0/0 (n=2)	6/60 (n=8)
Syzygium oleosum	Byron Bay	1	Y/N	Y	18/66 (n=1)	9/60 (n=9)
		2	N/N	Y	20/0 (n=2)	8/40 (n=8)
	Bongil Bongil NP	1	Y/N	Y	0/50 (n=1)	1/29 (n=9)
		2	Y/N	Y	0/11 (n=3)	8/26 (n=7)
	Bundjalung NP	1	N/Y	N	NA	9/74 (n=10)
	Strickland SF	1	Y/N	Y	20/31 (n=2)	14/50 (n=8)

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Macrozamia flexuosa C. Moore (Zamiaceae): a review of distribution, habitat and conservation status of an endemic cycad from the Hunter Region of New South Wales

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Abstract: A review has been undertaken of herbarium records, point location and full floristic data to assess the distribution, habitat and conservation status of *Macrozamia flexuosa* (Zamiaceae), a rare cycad endemic to the Hunter Region of New South Wales. Spatial analysis of all records (n=588) showed that the species is most prevalent on Permian-aged sediments but also occurs on older Carboniferous sediments and younger Triassic Narrabeen and Quaternary substrates. Point records intersect with a wide range of annual average rainfall bands (<700 to 1400 mm/yr), suggesting either that the species is tolerant of a variety of soil moisture gradients, or that current distribution may be representative of a differing climatic environment. Interpolation of database records (n=397) across 175,000 hectares of high-resolution vegetation mapping showed *Macrozamia flexuosa* to most frequently occur within the Lower Hunter Spotted Gum-Ironbark Forest (41%), followed by Kurri Sands Swamp Woodland (16%), Coastal Foothills Spotted Gum-Ironbark Forest (15%) and Coastal Plains Smooth-barked Apple Woodland (13%). Numerical analysis of full floristic plot data (n=86) largely supported these results, with the addition of Hunter Valley Moist Forest to these four regional communities.

A revised assessment of the conservation significance of *Macrozamia flexuosa* suggests that the existing conservation risk code of 2K be amended to 3RCa (distributional range >100km; rare but not immediately threatened; adequately conserved in at least 14 conservation reserves). An extent of occurrence of 6,319 km^2 and an area of occupancy of 696 km^2 have been determined for the species, and an estimated population size of between 1,740,000 and 43,500,000 individuals has been calculated. Under IUCN threat criteria, a code of NT (Near Threatened) is here considered appropriate for *Macrozamia flexuosa*, recognising uncertainties applicable to the assessment of Criteria A and B. It is noted, however, that *Macrozamia flexuosa* may currently be in slow decline due to as yet unknown limitations in flowering, pollination and/or dispersal mechanisms over a long period of time (many decades), with the longevity of individual specimens confounding any observable trends. A lack of demographic data relevant to these life traits limits comprehensive assessment, and further research to address these data gaps is recommended.

Key words: *Macrozamia flexuosa*, Hunter Valley, cycad, distribution, habitat, conservation status

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Introduction

The endemic Australian genus *Macrozamia* Miq. (Zamiaceae, Cycadales) currently supports 41 named species (https://cycadlist.org), the majority of which occur only in the eastern states. All species are long-lived and resilient plants, often occupying restricted or specialised habitats (Hill & Osborne 2004). In fire-prone environments, this resilience is commonly aided by a subterranean stem which shields the plant from hot temperatures while above-ground leaves are consumed. Pollination in *Macrozamia* and other cycads is effected either by obligate specialist weevils in the *Tranes* genus (Curculionidae) or thrips in the *Cycadothrips* genus (Aeolothripidae). Evidence suggests that both insects and cycads derive a mutual benefit from this association, and that specific weevils or thrips have a sole cycad host (Terry et al 2005). Several studies have examined seed dispersal and spread in *Macrozamia* (e.g. Ballardie & Whelan 1986; Burbidge & Whelan 1982; Snow & Walter 2007; Hall & Walter 2013); in the absence of vertebrate vectors the relatively heavy seed-bearing cones rely on gravity for the dispersal of seed. In one quantitative study in *Macrozamia miquelii* (F.Muell.) A.DC., Hall and Walter (2013), found that between 70-100% of 812 seeds remained within 1 m of parent plants, and the only predator observed to disperse seeds was the brushtail possum *Trichosurus vulpecula*. This mammal also predates and disperses the seed of *Macrozamia communis* L.A.S.Johnson (Ballardie & Whelan 1986) and *Macrozamia lucida* L.A.S.Johnson (Snow & Walter 2007), while Bush Rats (*Rattus fuscipes*) have also been implicated. The poor dispersal mechanism operating in many species of *Macrozamia* has led to development of a 'grove-forming' habit, where dense stands of plants progressively populate and dominate an area primarily through gravity (Hall & Walter 2013).

Macrozamia flexuosa C. Moore (Figure 1) lies within the *Parazamia* section of the genus, characterised by a generally small habit with 1-15 leaves in the crown, thick prominent veins on the lower surface of pinnae, mucilage canals being absent from pinnae, and the lower pinnae not reducing to spines (Hill & Osborne 2004). Within *Parazamia*, *Macrozamia flexuosa* is diagnosed by the erect, strongly spirally twisted leaves with long +/- terete petioles, and lax mid-green pinnae exhibiting involute margins (Hill 1998). The type specimen of *Macrozamia flexuosa* was collected by Ernst Betche in January 1883 from Limeburners Creek, near Karuah (Moore 1883). Endemic to the Hunter Valley region of New South Wales (Bulahdelah to Wyong, inland to Belford), *Macrozamia flexuosa* was originally considered a variety of *Macrozamia spiralis* (Salisb.) Miq. before transferal to *Macrozamia pauli-guilielmi* subsp. *flexuosa* (C.Moore) L.A.S. Johnson, and then raised to specific rank as *Macrozamia flexuosa* (Hill 1998).

Macrozamia flexuosa is considered rare but not threatened in New South Wales or Commonwealth threatened species legislation, and carries a conservation risk code of 2K (a poorly known plant species with a geographical distribution of less than 100km: Briggs & Leigh 1996). Taxa carrying the 'K' label such as this potentially remain at risk from habitat loss and clearing while ever their status remains formally unassessed and unknown. Studies over the last fifteen years have revealed a number of populations of *Macrozamia flexuosa* within secure conservation reserves (e.g. Werakata & Columbey National Parks: Bell 2004, 2009), yet there has been no quantification or conservation assessment of the species as a whole. Currently, and in contrast to current threatened species legislation in Australia, *Macrozamia flexuosa* is listed on the IUCN Red List as Endangered under Criterion A4c (Hill 2010; IUCN 2019), based on suspected population decline resulting from reductions in area of occupancy, extent of occurrence and/or habitat quality. At the time of that assessment, *Macrozamia flexuosa* was thought to number between 2,500 and 10,000 mature individuals, and to be threatened by over-collecting and land clearance. Only six years earlier, previous assessments (e.g. Hill & Osborne 2004) considered this species to be of Least Concern (LC).

In light of these differing conservations assessments of *Macrozamia flexuosa*, this paper reviews the distribution and habitat of this poorly known taxon, and formally assesses conservation significance. It addresses both the legacy conservation risk code applied by Briggs & Leigh (1996) and implements the IUCN threat criteria to determine a new threat status for this species.

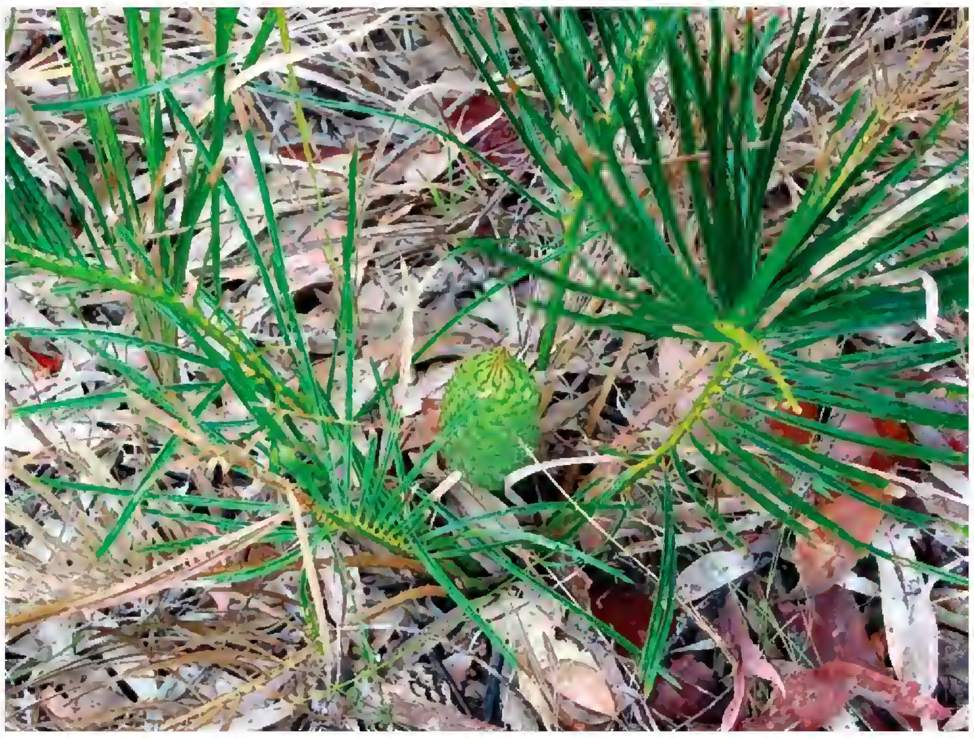

Fig 1. *Macrozamia flexuosa*, showing a male cone, growing in Werakata National Park.

Study Area

With the exception of a few presumed extinct individuals or unconfirmed records elsewhere, *Macrozamia flexuosa* occurs exclusively in the broader Hunter region (taken here as including the northern parts of the Central Coast) of central eastern New South Wales. This region includes the catchments of three major rivers; the Hunter and the Goulburn which converge near Muswellbrook in the west and flow east to the coast at Newcastle, and the Manning which flows to the coast near Taree (Figure 2). Although no formal boundary exists, the lower Hunter is generally considered to occur east from the Singleton district, and includes all or part of the local government areas (LGAs) of Central Coast, Cessnock, Dungog, Lake Macquarie, Maitland, Mid Coast, Newcastle, Port Stephens and Singleton. The Hunter region lies at the northern end of the Sydney geological basin, which extends south to Batemans Bay. The Sydney Basin is bounded to the north-east, south-east, west and north by geological unconformities and thrust lines, with development thought to have occurred over a long period of time, the final definitive movements of which occurred within the Late Triassic period (Bembrick et al 1973).

The Hunter Valley falls within a warm temperate climatic zone, with a maritime influence near the coast, and experiences warm wet summers and cool dry winters. Rainfall generally peaks in late Summer and early Autumn, although local variations due to topography are evident. Annual average rainfall ranges from 677 mm at Singleton, through 986 mm at Dungog, 1,122 mm at Newcastle and 1,350 mm at Gosford. Temperatures range from a monthly average low of 4.2° C in July to a high of 31.9° C in January, with both extremes recorded at Singleton (Bureau of Meteorology 2018).

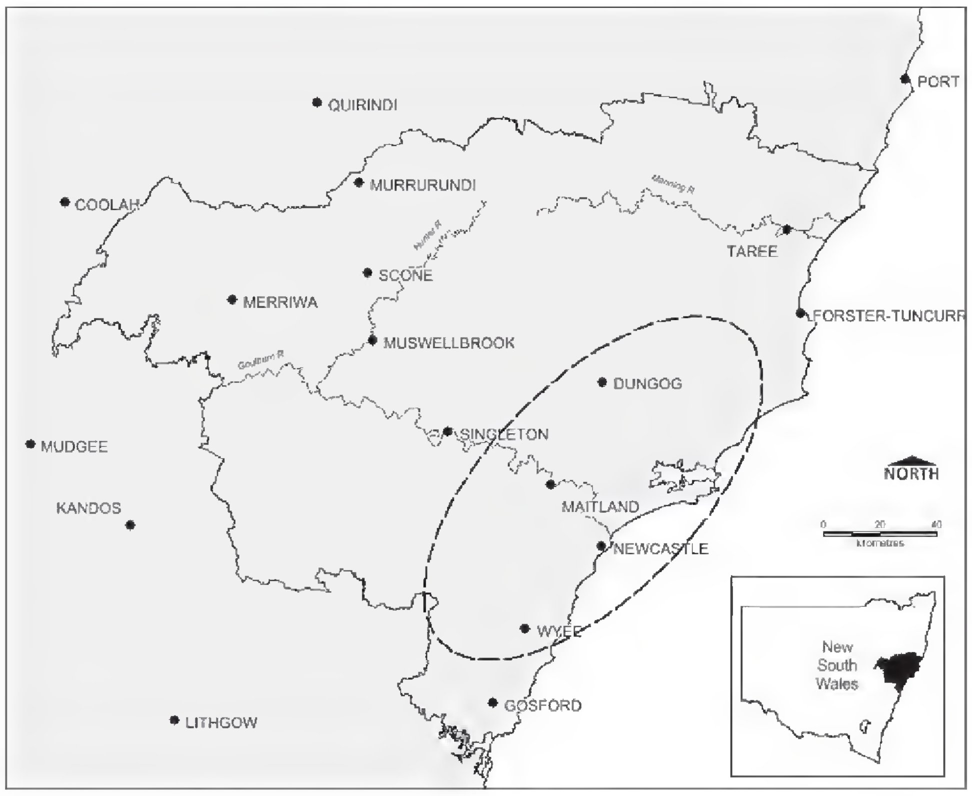

Fig 2. The study area, showing towns within the lower Hunter (ellipse) and broader Hunter region.

Methods

Existing and new populations

Existing records of *Macrozamia flexuosa* were extracted from personal databases and online records and collections within the New South Wales Office of Environment and Heritage *Bionet* database (http://www.bionet.nsw.gov.au/) and the Australian Virtual Herbarium (http://avh.chah.org.au/) (extracted November 2018). Duplicate records were removed from this combined dataset, after careful review of positional co-ordinates, associated written descriptions, collection accession numbers, and dates of observation.

A review was also made of the rapid point data generated as part of high-resolution sub-regional and special purpose vegetation mapping projects (e.g. DECC 2008; Bell 2009; Bell & Driscoll 2008, 2016; Bell & Carty 2012) to glean additional records of *Macrozamia flexuosa*. This dataset comprises 57,293 point locations from across the known distribution of *Macrozamia flexuosa* where dominant plant species and rare and significant taxa have been recorded. Although this data is not comprehensive across the full distribution of *Macrozamia flexuosa* (the bulk fall within Cessnock, Lake Macquarie and the Central Coast LGAs), it does act as a useful proxy in the absence of any other targeted survey data.

Habitat Assessment

Spatial Analysis

Occupied habitat for *Macrozamia flexuosa* was spatially assessed using Geographical Information System (GIS) analysis of point location data with broad environmental attributes, and against high resolution vegetation mapping where this was available (Table 1). For the former, point location data was overlain on available GIS layers for geology (Geoscience Australia) and a regional annual rainfall model developed from Bureau of Meteorology data (C. Driscoll, unpubl.), and univariate statistics applied to determine the most frequent combination of abiotic conditions supporting *Macrozamia flexuosa*. Recently completed high resolution vegetation mapping encompassing over 175,000 hectares of potential *Macrozamia flexuosa* habitat was used to determine the most frequent vegetation communities supporting the species. These mapping projects (Table 1, a subset of the total regional mapping effort) are built upon more than 42,000 ground control data points, and are consequently considered superior to other available vegetation maps which rely on modelling (e.g. NPWS 2000; Sivertsen et al 2012). Nicholls et al (2002) and Hunter (2015) provide reviews of such models, highlighting limitations in their use for conservation assessments.

Table 1. Available spatial data sources of high resolution mapping, used in GIS analysis of *Macrozamia flexuosa* point data.

Project	Source	Area (ha)
eastern Cessnock LGA	DECC 2008	65,690
Central Coast LGA (former Wyong LGA, west of M1 motorway)	Bell & Driscoll 2008	48,530
Lake Macquarie LGA	Bell & Driscoll 2016	38,557
Singleton Army Training Area	Bell & Carty 2012	14,470
Beresfield area (Stony Pinch)	Driscoll & Bell 2014	3,516
Salt Ash Weapons Range	Bell & Driscoll 2006	2,823
Columbey NP & SCA	Bell 2009, 2016	1,562
Total		175,148

Numerical Floristic Classification

Standard full floristic survey plots from areas supporting *Macrozamia flexuosa* were extracted from a regional database maintained by the author. Each plot of 0.04ha (nominally 20 x 20m) recorded all vascular plant species, and attributed each with a modified Braun-Blanquet (1928) cover abundance code (1 = <5% cover, few individuals; 2 = <5% cover, many individuals; 3 = 6-25% cover; 4 = 26-50% cover; 5 = 51-75% cover; 6 = 76-100% cover). Data from these plots were analysed using the Primer multivariate statistical program (v6, Clarke & Gorley 2006) to assist identification of occupied habitat for the species. The CLUSTER and MDS analysis modules were used to examine patterns within the dataset, while the SIMPER routine was used to identify diagnostic species groups. Where possible, defined habitats were then aligned to regional (NPWS 2000) vegetation communities. Plant nomenclature follows the New South Wales online flora PlantNET (http://plantnet.rbgsyd.nsw.gov.au/floraonline.htm).

Results

Extant populations

Regionally, 588 separate records of *Macrozamia flexuosa* were retrieved from database auditing, spread across nine local government areas of the lower Hunter (Figure 3). The oldest record was in 1881 from near Limeburners Creek (Port Stephens LGA), while the most recent was in 2018. Most records occurred within the Cessnock LGA (300), followed by Lake Macquarie (73), Port Stephens (57), Dungog (52), Singleton (34), Mid Coast (32), Maitland (9), Newcastle (8) and Central Coast (1) LGAs. One of these records lies north of Taree in Coorabakh National Park and may be in error or represent a highly disjunct population; field survey undertaken in that location by the author has recorded only *Macrozamia communis*. There is also an additional single record from Shoalhaven LGA, and four in Sydney (1 each in Cumberland and Woollahra LGAs, and 2 in Hornsby LGA), but these too may be in error and require further confirmation.

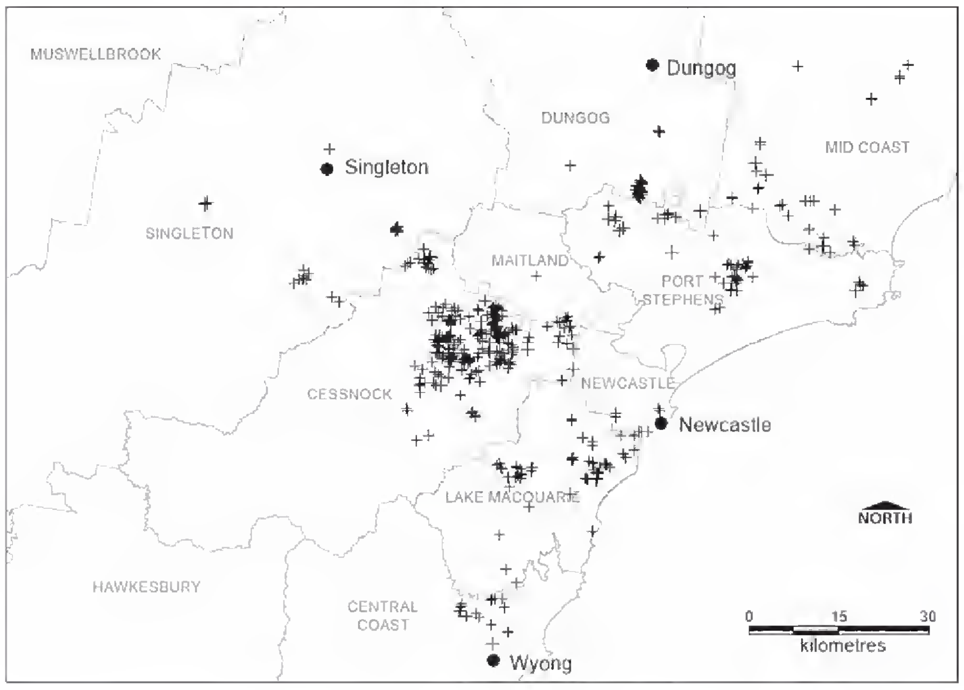

Fig 3. Distribution of *Macrozamia flexuosa* observations, from AVH and Bionet databases and personal records (n=588). Map excludes six outlying records in Mid Coast, Shoalhaven and three Sydney LGAs, which may be extinct, in error or represent disjunct and outlying populations.

Assessment of Abiotic Habitat

Spatial analysis showed that most records (89%) of *Macrozamia flexuosa* occur on a variety of sediments of Permian (73%) and Carboniferous (16%) age (Figure 4). Permian-aged sediments are typically comprised of highly erodible fine-grained sedimentary strata and some conglomerates and sandstones. The Newcastle Coal Measures (Pon; 13% of regional records) comprise coal seams, claystones, siltstones, sandstones and conglomerate. Similarly, fine-grained material comprising the Branxton Formation (Psab; 19%), the Farley Formation (Psdf; 12%) and the Rutherford Formation (Psdr; 10%), collectively support 41% of *Macrozamia flexuosa* records in the region. The Wallaringa Formation (Cswa) within the Carboniferous sediments, which shows as the most important unit within these older sediments (8% regional records), comprises thickly bedded lithic sandstone, conglomerate and some granitoids. These records nearly all emanate from a survey of Columbey National Park (Bell 2009), and consequently may be prominent in the spatial analysis due to sampling bias.

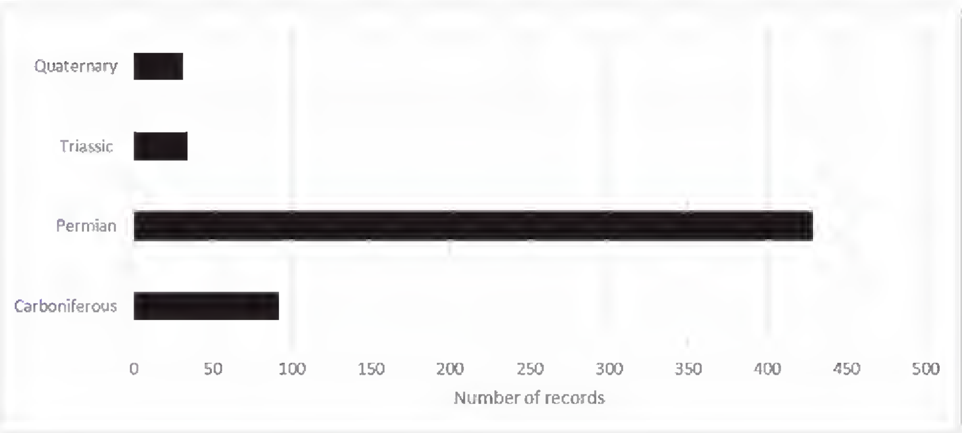

Fig 4. Distribution of *Macrozamia flexuosa* records across major geological strata from the species' full distributional range (n=588).

Analysis of annual rainfall (Figure 5) shows that the bulk of regional *Macrozamia flexuosa* records (93%) fall within the 700-1200mm rainfall band, with a small number of records also present at the extremes (<700mm & >1300mm). This wide range of annual rainfall suggests that the distribution of this species may not be determined or limited by soil moisture availability. Note that the apparent bimodal result shown in the regional rainfall distribution may be attributable to the absence of a comprehensive database of records across the full range of *Macrozamia flexuosa*.

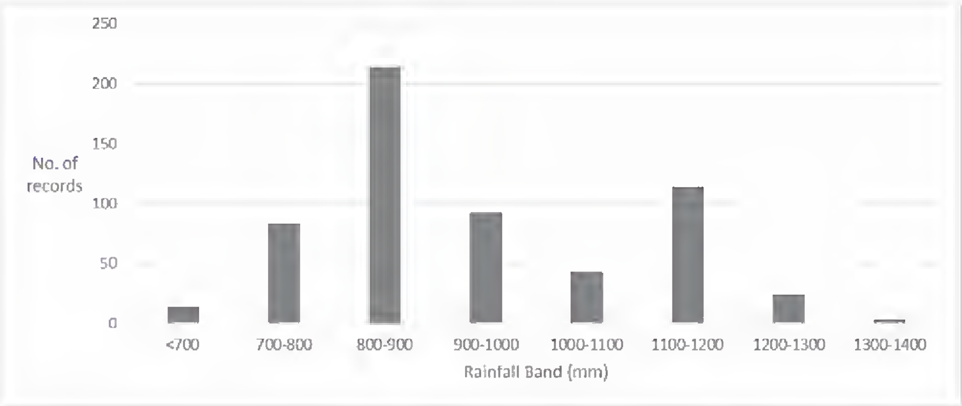

Fig 5. Distribution of *Macrozamia flexuosa* records across annual rainfall bands (n=588).

Assessment of Floristic Communities

Spatial Analysis

Spatial analysis of 397 *Macrozamia flexuosa* records was possible across seven areas of high resolution mapping, totalling c. 175,000 hectares (Table 2). This represents nearly 70% of the total 588 records of *Macrozamia flexuosa* across its entire range, and consequently can be considered a reasonably good representation of occupied habitat for this species. All high-resolution mapping has employed a consistent community nomenclature, and one that can be readily grouped back to the widely-used regional NPWS (2000) classification. For discussion purposes, occupied habitat of *Macrozamia flexuosa* is cased within this NPWS (2000) regional classification. Four high-resolution communities (Cockle Creek Dune Forest, Ellalong Grey Gum-Stringybark-Apple Forest, Quorrobolong Scribbly Gum Forest, Sandstone Hills Bloodwood Woodland) have no NPWS (2000) equivalent, so have been retained in the analysis (Figure 6).

The most frequent regional vegetation type supporting *Macrozamia flexuosa* was found to be the Lower Hunter Spotted Gum-Ironbark Forest (41% of 397 records). Three other regional units follow this with between 13 and 16% of all records; Kurri Sands Swamp Woodland (16%), Coastal Foothills Spotted Gum-Ironbark Forest (15%) and Coastal Plains Smooth-barked Apple Woodland (13%). A further 13 regional communities also support the species, but only between 0.3 and 4% of records, and four communities not defined in NPWS (2000) support between 0.5 and 1.3% of records.

Table 2. Available spatial data sources of high resolution mapping, used in spatial analysis of *Macrozamia flexuosa* point data.

Project	Source	No. *Macrozamia* records
eastern Cessnock LGA	DECC 2008	237
Lake Macquarie LGA	Bell & Driscoll 2016	66
Columbey NP	Bell 2009	38
Salt Ash Weapons Range	Bell & Driscoll 2006	26
Beresfield area (Stony Pinch)	Driscoll & Bell 2014	13
Singleton Army Training Area	Bell & Carty 2012	10
Central Coast LGA (west of M1 motorway)	Bell & Driscoll 2008	7
Total		397

Floristic Analysis

Eighty six sample plots were found to support *Macrozamia flexuosa* during the auditing process, spread across the range of the species (Figure 7). Numerical analysis of these 86 sites revealed eight regional (NPWS 2000) and one transitional (DECC 2008) vegetation community where *Macrozamia flexuosa* is present (Figure 8). For six of the nine defined regional communities, *Macrozamia flexuosa* contributed between 3 and 5% of the total floristic diversity for each community, and was within the top 11 important species for those communities (Table 3). For the Seaham Spotted Gum-Ironbark Forest, *Macrozamia flexuosa* contributed only 2.16% and was less important, while Coastal Plains Scribbly Gum Woodland and Sandstone Grey Myrtle Sheltered Forest showed negligible (<0.1%) contribution. Based on the available dataset of full floristic plot data, important regional habitat for *Macrozamia flexuosa* include those broadly defined as Spotted Gum-Ironbark associations (unit 12, 15, 16 & 17), and those where *Angophora* species on sandy clays or clay loams occur (units 30 & 35). Other habitats where *Macrozamia flexuosa* may be present evidently support few populations of limited size. Floristic compositions of habitat for these nine communities, as determined through SIMPER analysis, are contained in Appendix 1.

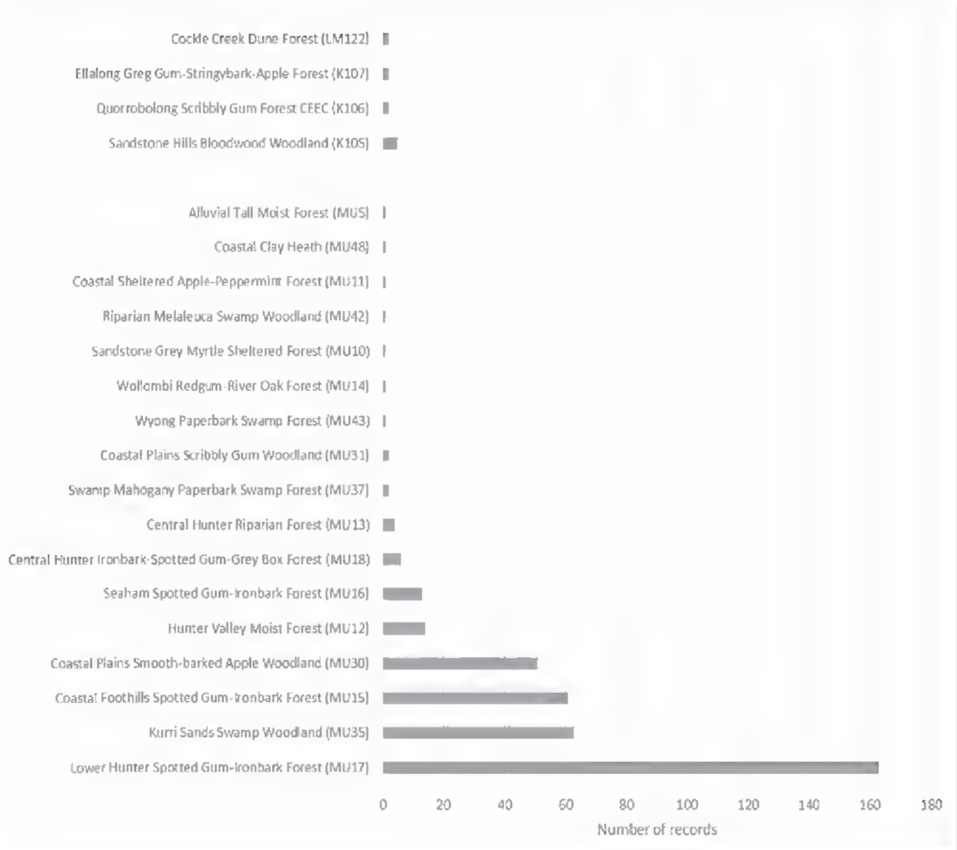

Fig 6. Distribution of *Macrozamia flexuosa* records across available high-resolution vegetation mapping (n=397). Community nomenclature follows NPWS (2000) for all but the upper four communities, which are as reported in sub-regional studies (see Table 1). MU = Map Unit (NPWS 2000); K = Cessnock-Kurri subregional study (DECC 2008); LM = Lake Macquarie subregional study (Bell & Driscoll 2016).

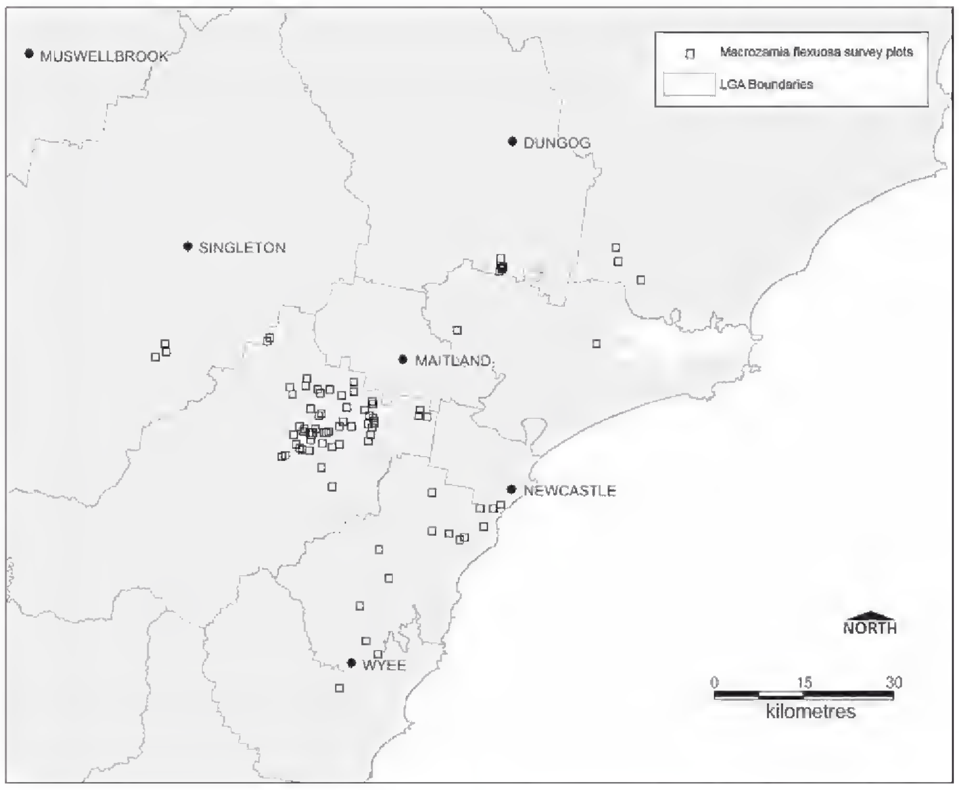

Fig 7. Distribution of sample plots supporting *Macrozamia flexuosa*, as used in the regional numerical analysis for habitat profiling (n=86).

Table 3. Percentage contribution and importance rank of *Macrozamia flexuosa* within nine defined regional communities (habitats), in decreasing order of % contribution.

Regional Community (NPWS 2000)	% Contribution	Importance Rank
Lower Hunter Spotted Gum-Ironbark Forest (Unit 17)	4.53	7
Hunter Valley Moist Forest (Unit 12)	4.44	6
Kurri Sands Swamp Woodland (Unit 35)	3.56	6
Coastal Plains Smooth-barked Apple Woodland (Unit 30)	3.45	6
Coastal Foothills Spotted Gum-Ironbark Forest (Unit 15)	3.42	9
Lower Hunter Spotted Gum-Ironbark Forest (Transition) (Unit 17)	3.24	11
Seaham Spotted Gum-Ironbark Forest (Unit 16)	2.16	23
Coastal Plains Scribbly Gum Woodland (Unit 31)	-	-
Sandstone Grey Myrtle Sheltered Forest (Unit 10)	-	-

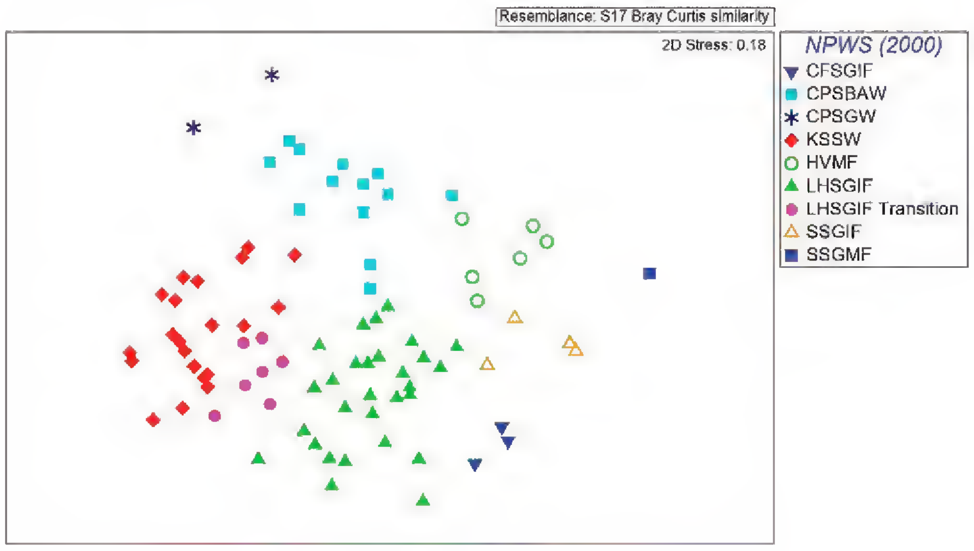

Fig 8. MDS ordination of 86 floristic sites supporting *Macrozamia flexuosa*, generated through the Primer analysis, and classified to the NPWS (2000) regional classification. Key: CFSGIF = Coastal Foothills Spotted Gum-Ironbark Forest; CPSBAW = Coastal Plains Smooth-barked Apple Woodland; CPSGW = Coastal Plains Scribbly Gum Woodland; KSSW = Kurri Sands Swamp Woodland; HVMF = Hunter Valley Moist Forest; LHSGIF = Lower Hunter Spotted Gum-Ironbark Forest; SSGIF = Seaham Spotted Gum-Ironbark Forest; SSGMF = Sandstone Grey Myrtle Sheltered Forest.

Each community can be briefly summarised as:

1. **Lower Hunter Spotted Gum-Ironbark Forest (Unit 17)** – Commensurate with the Endangered Ecological Community of the same name, typified by a canopy of *Corymbia maculata* and *Eucalyptus fibrosa*, over an understorey of prickly shrubs such as *Daviesia ulicifolia, Bursaria spinosa* and *Melaleuca nodosa*. Ground layer vegetation includes the grasses *Entolasia stricta, Aristida vagans* and *Themeda triandra*. *Macrozamia flexuosa* is locally common and widespread in this habitat, and in some areas co-occurs with *Macrozamia reducta*.

2. **Hunter Valley Moist Forest (Unit 12)** – Hunter Valley Moist Forest is a more sheltered form of the wider ranging Spotted Gum-Ironbark associations, and is typified in the canopy by *Corymbia maculata, Eucalyptus punctata, Eucalyptus acmenioides* and *Eucalyptus paniculata* or *Eucalyptus siderophloia*. Common understorey components include *Myrsine variabilis, Notelaea longifolia, Pittosporum undulatum, Polyscias sambuccifolia, Breynia oblongifolia* and *Persoonia linearis*. *Macrozamia flexuosa* can be locally common in this community type, but more often it is present as scattered individuals only.

3. **Kurri Sands Swamp Woodland (Unit 35)** - Broadly encompassed by the Endangered Ecological Community of the same name, this community occupies broad sandy plains, low ridgelines and clay-loam basins in the Cessnock to Kurri Kurri area of the lower Hunter. It supports a variable composition of open or scrubby forests of *Angophora bakeri, Eucalyptus parramattensis* subsp. *decadens, Corymbia gummifera, Eucalyptus racemosa, Eucalyptus fibrosa* and *Eucalyptus* sp aff *agglomerata* with a shrubby or grassy understorey. DECC (2008) have described five variants of Kurri Sands Swamp Woodland, and *Macrozamia flexuosa* can occur in any of these as widely spaced individuals.

4. **Coastal Plains Smooth-barked Apple Woodland (Unit 31)** – An open forest or woodland typified by the presence of *Angophora costata* in the canopy, but with co-occurring species also including *Corymbia gummifera, Eucalyptus umbra* and in some areas *Eucalyptus piperita* and/or *Eucalyptus haemastoma*. Understorey vegetation is generally shrubby and comprises various *Acacia* spp. and peas (*Pultenaea, Daviesia*), *Banksia collina* and *Leptospermum trinervium*. Within this habitat, *Macrozamia flexuosa* occurs as scattered individuals or small groups of plants, but never dominates the ground layer vegetation.

5. **Coastal Foothills Spotted Gum-Ironbark Forest (Unit 15)** – An open forest occurring on the foothills adjacent to the coastal plains. Dominant canopy species include *Corymbia maculata, Eucalyptus paniculata, Eucalyptus punctata, Eucalyptus fergusonii, Eucalyptus umbra* and/or *Eucalyptus siderophloia*, over an understorey of species such as *Bursaria spinosa, Podolobium ilicifolium, Daviesia squarrosa, Notelaea longifolia* and *Persoonia linearis*. *Macrozamia flexuosa* is present in this habitat as scattered individuals or small groups of plants.

6. **Lower Hunter Spotted Gum-Ironbark Forest - Transitional (included in Unit 17)** - The Lower Hunter Spotted Gum-Ironbark Forest Transition group shown on Figure 8 is representative of the Sandstone Hills Transition Forest (MU105b) from the Cessnock area (DECC 2008). Although not defined in NPWS (2000), this type occurs on resistant sandstones of Permian age, and can be considered a form of Lower Hunter

Spotted Gum-Ironbark Forest. Common canopy species in this group include *Corymbia maculata, Corymbia eximia, Eucalyptus fibrosa, Eucalyptus capitellata* and *Corymbia gummifera*. *Macrozamia flexuosa* can be reasonably common in this habitat, but is often localised.

7. **Seaham Spotted Gum-Ironbark Forest (Unit 16)** – An open forest occurring generally north of the Hunter River, and dominated in the canopy by a range of eucalypts but *Corymbia maculata, Eucalyptus siderophloia*, and *Eucalyptus acmenioides* are generally abundant. Grasses and herbs dominate the ground layer, particularly *Microlaena stipoides*, and *Macrozamia flexuosa* occurs occasionally as individuals or in very small groups.
8. **Coastal Plains Scribbly Gum Woodland (Unit 31)** – An open forest or woodland characterised by *Eucalyptus haemastoma, Corymbia gummifera, Eucalyptus capitellata* and *Angophora inopina* in the canopy, over a heathy understorey of species such as *Banksia collina, Lambertia formosa, Leptospermum trinervium, Isopogon anemonifolius* and *Pultenaea tuberculata*. *Macrozamia flexuosa* is very rare in this habitat, and weight of records relative to survey effort suggests that this is marginal habitat.
9. **Sandstone Grey Myrtle Sheltered Forest (Unit 10)** – A gully forest dominated by *Backhousia myrtifolia* in the mid-layer, under emergent eucalypts. Ground layer vegetation is typically sparse due to the shading effect of the *Backhousia* canopy, but commonly includes ferns such as *Doodia aspera* and *Pellaea falcata*. This habitat is relatively rare towards the coastal parts of the region, but becomes better developed in inland areas where rainfall is less. *Macrozamia flexuosa* is very rare in this community type, and occurs only where it adjoins more favourable habitat.

Discussion

Regional Habitat

Two complementary methods have been used in this study to provide an assessment of habitat for *Macrozamia flexuosa*: spatial GIS analysis of a cleaned dataset of herbarium collections and observation records against environmental and locally-accurate vegetation mapping, and numerical analysis of full floristic plot data. Both methods have captured an array of existing and new data to identify habitat and vegetation communities currently supporting *Macrozamia flexuosa*. Collectively, these two methods have identified key habitats and vegetation communities for the species, summarised in Table 4 and Table 5.

In the spatial analysis, it was shown that *Macrozamia flexuosa* occurs most prevalently on Permian-aged sediments (principally the Branxton, Farley and Rutherford Formations). Older Carboniferous sediments (particularly the Wallaringa Formation) are also well represented in the data, although this is likely the result of previous concentrated survey effort within Columbey National Park (Bell 2009). Smaller occurrences are also evident within the younger Triassic Narrabeen and Quaternary sediments. A wide spread in annual average rainfall received was evident for areas supporting *Macrozamia flexuosa*, ranging from <700mm/yr to ~1400mm/yr. This suggests either that the distribution of this species is not limited or determined by available soil moisture, and that it is tolerant of a wide range of moisture environments, or that current-day populations are representative of a former environment with a different climate. Other studies (e.g. Preece et al 2007; Binns & Meek 2008) have shown a link between *Macrozamia* distribution and high moisture availability, although in the present study the largest populations of *Macrozamia flexuosa* occur in the drier habitats. Working on *Macrozamia lucida*, Kaye et al (2016) found a correlation between plant distribution and elevated moisture (relative humidity at the ground surface), but conceded that current-day distribution may represent a contraction from a formerly wider range under differing climatic regimes, rather than reliance on available moisture.

Table 4. Summary of GIS analysis of environmental attributes supporting *Macrozamia flexuosa* (n=588).

Attribute	Key elements (% of dataset)
Geological Age	Permian (73%)
	Carboniferous (16%)
	Triassic (6%)
	Quaternary (5%)
Geological Formation	Branxton Formation (Psab) (19%)
	Newcastle Coal Measures (Pon) (13%)
	Farley Formation (Psdf) (12%)
	Rutherford Formation (Psdr) (10%)
	Wallaringa Formation (Cswa) (8%)
Annual Rainfall (mm/yr)	800-900 (37%)
	1100-1200 (19%)
	900-1000 (16%)
	700-800 (14%)
Vegetation Type (GIS analysis)	Lower Hunter Spotted Gum-Ironbark Forest (MU17) (41%)
	Kurri Sands Swamp Woodland (MU35) (16%)
	Coastal Foothills Spotted Gum-Ironbark Forest (MU15) (15%)
	Coastal Plains Smooth-barked Apple Woodland (MU30) (13%)
	Hunter Valley Moist Forest (MU12) (4%)
	Seaham Spotted Gum-Ironbark Forest (MU16) (3%)

Table 5. Summary of numerical analysis of habitats (floristic type) supporting *Macrozamia flexuosa* (n=86). Nomenclature follows NPWS (2000).

Primary Habitats	*Secondary Habitats*
Lower Hunter Spotted Gum-Ironbark Forest (MU17)	Seaham Spotted Gum-Ironbark Forest (MU16)
Hunter Valley Moist Forest (MU12)	Coastal Plains Scribbly Gum Woodland (MU31)
Kurri Sands Swamp Woodland (MU35)	Sandstone Grey Myrtle Sheltered Forest (MU10)
Coastal Plains Smooth-barked Apple Woodland (MU30)	
Coastal Foothills Spotted Gum-Ironbark Forest (MU15)	
Lower Hunter Spotted Gum-Ironbark Forest (Transition) (MU17)	

Interpolation of database records across 175,000 hectares of high-resolution vegetation mapping showed that *Macrozamia flexuosa* has been most frequently recorded within the Lower Hunter Spotted Gum-Ironbark Forest (41% of 397 records), followed by Kurri Sands Swamp Woodland (16%), Coastal Foothills Spotted Gum-Ironbark Forest (15%) and Coastal Plains Smooth-barked Apple Woodland (13%). The remaining 15% of records are spread across a further thirteen regional and four subregional communities, each supporting less than 4% of records. The first two of these (Lower Hunter Spotted Gum-Ironbark Forest and Kurri Sands Swamp Woodland), collectively support 57% of all records and equate to threatened ecological communities protected under the NSW *Biodiversity Conservation Act 2016*.

Numerical analysis of full floristic plot data highlighted the importance of five regionally-defined vegetation communities for *Macrozamia flexuosa*, which largely supported results obtained in the spatial analysis: the Lower Hunter Spotted Gum-Ironbark Forest (Unit 17, & including a transitional form from Cessnock LGA), Hunter Valley Moist Forest (Unit 12), Kurri Sands Swamp Woodland (Unit 35), Coastal Plains Smooth-barked Apple Woodland (Unit 30), and Coastal Foothills Spotted Gum-Ironbark Forest (Unit 15). For all five of these communities, *Macrozamia flexuosa* contributes 3-5% of the diversity of all species present, and ranked in the top ten most important taxa for each community. Other less important regional communities include Seaham Spotted Gum-Ironbark Forest (Unit 16), Coastal Plains Scribbly Gum Woodland (Unit 31) and Sandstone Grey Myrtle Sheltered Forest (Unit 10).

Conservation Assessment

Reserve Representation

Macrozamia flexuosa is currently represented in fourteen secure conservation reserves throughout its range, across nine local government areas (Table 6). The species is also present in several of the State Forests around the Cessnock and Port Stephens region, including Cessnock, Aberdare and Medowie State Forests, and is informally protected in the Salt Ash Weapons Range and Singleton Army Training Area, both managed by the Commonwealth Department of Defence. Based on weight of records, Werakata, Columbey and Belford National Parks provide important habitat for the species, representing 82% of all observations made within conservation estate; collectively all reserves protect only 28% of records across the region.

Table 6. Representation of *Macrozamia flexuosa* within conservation reserve and local government areas, based on GIS analysis of point data (n=588), shown in decreasing order of importance.

Reserve	LGA	No. records
Werakata National Park	Cessnock	69
Columbey National Park	Dungog / Port Stephens	48
Belford National Park	Singleton	16
Werakata State Conservation Area	Cessnock	6
Lake Macquarie State Conservation Area	Lake Macquarie / Central Coast	5
Glenrock State Conservation Area	Lake Macquarie / Newcastle	4
Karuah Nature Reserve	Mid Coast / Port Stephens	4
Sugarloaf State Conservation Area	Lake Macquarie / Cessnock	3
Wallaroo National Park	Dungog / Port Stephens	2
Coorabakh National Park	Mid Coast	1
Medowie State Conservation Area	Port Stephens	1
Pambalong Nature Reserve	Newcastle	1
Pulbah Island Nature Reserve	Lake Macquarie	1
Watagans National Park	Cessnock / Lake Macquarie	1
Total		**162**

Conservation Risk Code

Briggs and Leigh (1996), during the last revision to the conservation risk codes for Australian plant species, attributed *Macrozamia flexuosa* with a code of 2K, indicating a poorly known taxon with a distributional range of less than 100 km. In the light of new information on distribution and reserve presence, it is appropriate to now review this coding and threat criteria to the species. Excluding the six highly disjunct records of *Macrozamia flexuosa* present in the Mid Coast, Shoalhaven and Sydney districts, the species currently occupies a distributional range of 120 km (maximum distance between current records). Additionally, *Macrozamia flexuosa* is present within fourteen conservation reserves which collectively are likely to well exceed 1,000 individual plants (162 point locations). Threats within these reserves are few, but in other land tenures the potential for habitat clearing and development remains current. Following the Briggs and Leigh (1996) system, this suggests that a revised conservation risk code of 3RCa is most suitable (i.e. a rare species with a geographical distribution of >100 km, and adequately represented by >1,000 mature individuals within secure conservation reserves).

IUCN Criteria Assessment

An IUCN code of Endangered (EN) is currently applied to *Macrozamia flexuosa* in the IUCN Red List (Hill 2010; IUCN 2019), yet the species is currently not listed in threatened species legislation within New South Wales or Australia. As has been found with some other Red List *Macrozamia* occurring across restricted ranges (e.g. *Macrozamia johnsonii* D.L.Jones & K.D.Hill, Binns & Meek 2008; *Macrozamia platyrhachis* F.M.Bailey, Terry et al 2008), there is little justification or explicit documentation as to why such a listing has been determined. Interestingly, previous assessments (e.g. Hill & Osborne 2004, using 1994 IUCN categories modified to accommodate long-lived perennial plants) considered *Macrozamia flexuosa, Macrozamia platyrhachis* and *Macrozamia johnsonii* to be of Least Concern (LC), and not at risk.

A revised conservation assessment following the guidelines of IUCN (2017) has now been undertaken for *Macrozamia flexuosa*, using the data and observations discussed in this paper (Appendix 2). Although a rare taxon, *Macrozamia flexuosa* fails to meet any of the five IUCN criteria for any threatened category. For Criterion A, estimates exceeding the thresholds of the past or expected reduction in population sizes over 60 years (three generations) have been made, but these are subjective in nature and may change should a more quantitative assessment of habitat loss over this time period be undertaken. For Criterion B, data on population attributes could not meet two out of three sub-criteria to trigger a listing as Endangered or Vulnerable on distribution grounds, despite the primary criterion of extent of occurrence and area of occupancy being met. Best estimates for population size clearly exceed the thresholds for both Criteria C and D, and a quantitative analysis required under Criterion E is not possible due to data limitations.

Under IUCN (2017) criteria, and following the conclusions noted above, a code of NT (Near Threatened) is here considered appropriate for *Macrozamia flexuosa*, recognising some of the uncertainties applicable to the assessment of Criteria A and B. This finding is in contrast to the current Red List determination of Endangered for this taxon (IUCN 2019), but is consistent with other studies on *Macrozamia* that have questioned listings of Endangered on the IUCN Red List (Binns & Meek 2008; Terry et al 2008). Depending on the extent of land clearing and development in existing habitat that may continue in coming decades, detailed population estimates and a review of the NT coding for *Macrozamia flexuosa* may be necessary.

Further Research

Macrozamia flexuosa is clearly a species that is widespread within its relatively restricted geographical distribution (c. 6,300 km^2), yet appears to exist predominantly as scattered individuals or small groups in most habitats. The grove-forming habit of other *Macrozamia*, as outlined in Hall and Walter (2013), does not seem to be typical for *Macrozamia flexuosa* at many of the known sites. This, together with anecdotal observations of limited cone production and seedling presence in many populations, suggest that there may be some reproductive and dispersal limitations acting on this species, effects of which are masked by the longevity of mature individuals. A demographic and reproductive study of this species would be beneficial in this regard, and the methods devised by Borsboom et al (2015) for assessing population structure through leaf traits may apply well to *Macrozamia flexuosa*.

No research has yet been undertaken on pollination in *Macrozamia flexuosa* although Forster et al 1994 have identified obligate specialist weevils *Tranes* spp. for *Macrozamia pauli-guilielmi* (the species in which *Macrozamia flexuosa* was formerly considered a subsp.); this is an avenue for further research. An absence of appropriate insect pollinators may help to explain the apparent lack of fruiting and dispersal in *Macrozamia flexuosa*, and management to retain this pollinator in the environment may be required.

Additionally, as with all *Macrozamia* species the dispersal of seed is highly localised due to their large size and the scarcity of dispersal mechanisms. Some studies (Ballardie & Whelan 1986; Snow & Walter 2007; Hall & Walter 2013) have found that Common Brushtail Possum (*Trichosurus vulpecula*) and Bush Rats (*Rattus fuscipes*) consumed or carried *Macrozamia* seed away from mature plants, but dispersal rarely exceeded one metre. Burbidge and Whelen (1982) recorded dispersal distances of up to 40 cm for *Macrozamia riedlei* (Gaudich.) C.A.Gardner (very rarely up to 24 m), Hall and Walter (2013) reported one metre for *Macrozamia miquelii* (rarely up to 5 m), and Terry et al (2008) found no evidence of dispersal in *Macrozamia platyrhachis*. For *Macrozamia communis*, Ballardie and Whelan (1986) recorded dispersal distances of up to 2 m for the vast majority of studied seeds, but also noted that dispersal was lower in masting (i.e. synchronous cone or seed production) populations than non-masting populations. Evidently, in the absence of a sufficient predatory mammalian population gravity remains a prime dispersal agent for *Macrozamia flexuosa*. This, coupled with the apparent low rate of seed production, suggests that the spread of this species into currently unoccupied yet apparently suitable habitat is unlikely. Incidental observations at Columbey National Park show partially consumed seeds of *Macrozamia flexuosa* (Figure 9) within 1 m of adult plants, although the identity of the predator in this case is unknown.

Although current knowledge on population size and the extent of occurrence of *Macrozamia flexuosa* suggest an IUCN status of Near Threatened, it is plausible that this species may currently be in slow decline due to limitations in phenology, pollination, or dispersal mechanisms over a long time period (many decades), with the longevity of individual specimens confounding any observable trends (cf. Terry et al 2008 for *Macrozamia platyrhachis*). Research on the topics noted above will go some way towards clarifying the situation for *Macrozamia flexuosa*, particularly in regard to quantifying recruitment and how that may impact on IUCN assessments of observable continuing decline, as captured within Criterion A. Re-assessment of this taxon following any new information gained on pollination and dispersal is recommended, particularly if clearing and fragmentation within prime habitats accelerates beyond current expectations.

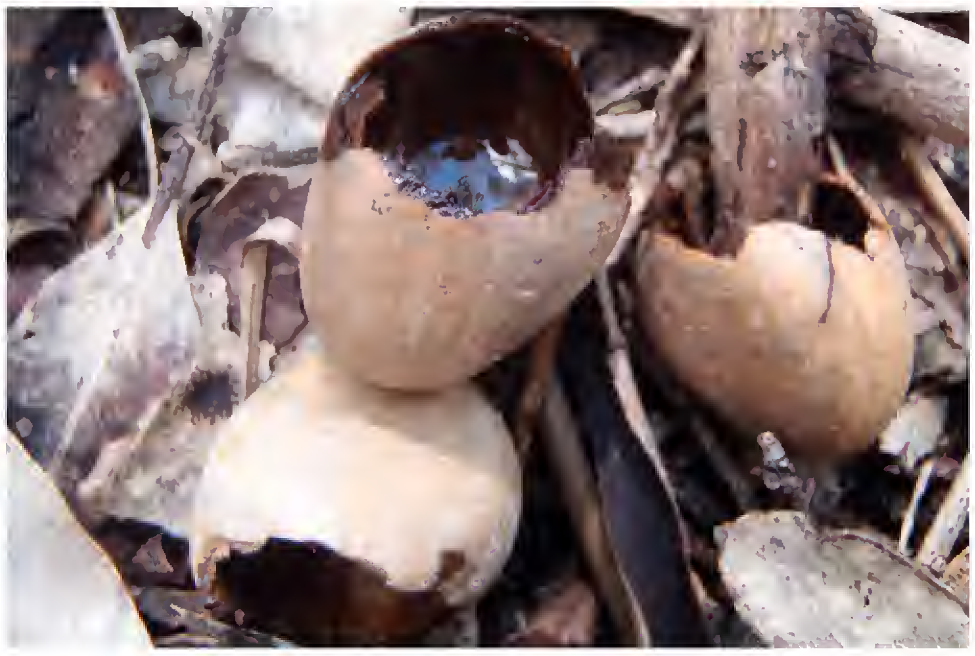

Fig 9. Seed of *Macrozamia flexuosa* following partial consumption, presumably by a mammalian predator (Columbey National Park).

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Appendix 1 Floristic Group Simper Analysis

The derivation of diagnostic species for each floristic group has been determined using the SIMPER routine in Primer (Clarke & Gorley 2006). SIMPER analysis provides the relative contributions of each taxon to the Bray-Curtis similarity within each of the defined floristic groups. Only those taxa contributing to a total cumulative contribution of 90% of the average similarity (ie: the value shown at the top of each table) for each community are listed. These taxa can be described of as typical of that group, and have a consistently large presence within the data as reflected in the ratio of their contribution to the standard deviation (the Sim/SD field in each table) across the within-group similarities (the average similarity). Groups with less than two samples (i.e. Sandstone Grey Myrtle Sheltered Forest) cannot be analysed in this way, and are therefore not presented.

In the diagnostic species tables:

- **Average similarity** is the within-group similarity for all pairs of sample plots comprising the group. Higher average similarity indicates a better defined group.
- **Av.Abund** is the average cover abundance of that species within sample plots comprising the group
- **Av.Sim** is the average similarity (contribution) made by each species to the within-group similarity (the overall average similarity).
- **Sim/SD** is the ratio of average similarity to standard deviation for each species across all pairs of samples. A high ratio represents a good discriminating species. At least three samples are required for this ratio to be calculated.
- **Contrib%** is the percentage contribution of each species to the overall average similarity for the group.
- **Cum.%** is the cumulative percentage contribution to the overall average similarity for the group.

Lower Hunter Spotted Gum-Ironbark Forest **(LHSGIF)**
Average similarity: 35.60

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Corymbia maculata	2.59	2.78	1.35	7.8	7.8
Aristida vagans	2.1	2.44	2.02	6.84	14.64
Eucalyptus fibrosa	2.38	2.25	0.94	6.32	20.96
Entolasia stricta	2.1	2.08	1.31	5.85	26.81
Lepidosperma laterale	1.79	2.05	1.82	5.75	32.56
Cheilanthes sieberi subsp. *sieberi*	1.55	1.7	1.45	4.76	37.32
Macrozamia flexuosa	**1.38**	**1.61**	**3.13**	**4.53**	**41.85**
Phyllanthus hirtellus	1.41	1.43	1.13	4.02	45.87
Lomandra multiflora subsp. *multiflora*	1.28	1.18	1.04	3.31	49.17
Eragrostis brownii	1.31	1.17	1.01	3.28	52.46
Pomax umbellata	1.24	1.07	0.85	2.99	55.45
Grevillea montana	1.17	1.02	0.83	2.86	58.31
Panicum simile	1.28	0.97	0.78	2.73	61.04
Melaleuca nodosa	1.86	0.9	0.43	2.54	63.58
Bursaria spinosa	1.34	0.79	0.57	2.21	65.79
Dianella revoluta var. *revoluta*	0.93	0.72	0.78	2.03	67.81
Microlaena stipoides var. *stipoides*	1.07	0.7	0.67	1.96	69.77
Lomandra filiformis subsp. *coriacea*	0.97	0.69	0.64	1.95	71.72
Glycine clandestina	0.97	0.62	0.6	1.73	73.45
Persoonia linearis	0.86	0.58	0.74	1.64	75.09
Daviesia ulicifolia subsp. *ulicifolia*	1.03	0.52	0.51	1.47	76.56
Lissanthe strigosa subsp. *subulata*	0.86	0.48	0.48	1.35	77.91
Themeda triandra	1.24	0.46	0.4	1.28	79.19
Denhamia silvestris	0.66	0.42	0.57	1.18	80.37
Aristida ramosa	1	0.39	0.37	1.08	81.45
Pratia purpurascens	0.76	0.35	0.46	0.98	82.43
Imperata cylindrica	0.79	0.34	0.4	0.95	83.39
Cymbopogon refractus	0.79	0.34	0.41	0.95	84.34
Paspalidium distans	0.72	0.27	0.34	0.75	85.09
Acacia ulicifolia	0.66	0.25	0.41	0.7	85.79
Vernonia cinerea var. *cinerea*	0.59	0.24	0.43	0.69	86.48

Lower Hunter Spotted Gum-Ironbark Forest **(LHSGIF)**

Average similarity: 35.60

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cassytha glabella f. glabella	0.52	0.22	0.38	0.62	87.1
Lomandra longifolia	0.55	0.21	0.37	0.58	87.68
Billardiera scandens	0.52	0.2	0.38	0.56	88.24
Pultenaea spinosa	0.48	0.19	0.28	0.53	88.77
Lomandra confertifolia subsp. *pallida*	0.59	0.19	0.26	0.52	89.29
Dendrophthoe vitellina	0.38	0.18	0.39	0.51	89.8
Eucalyptus umbra	0.59	0.16	0.26	0.45	90.25

Coastal Foothills Spotted Gum-Ironbark Forest **(CFSGIF)**

Average similarity: 33.88

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Bursaria spinosa	2	2.32	112.72	6.84	6.84
Cheilanthes sieberi subsp. *sieberi*	2	2.32	112.72	6.84	13.67
Cymbopogon refractus	2	2.32	112.72	6.84	20.51
Gahnia aspera	2	2.32	112.72	6.84	27.35
Microlaena stipoides var. *stipoides*	2.67	2.32	112.72	6.84	34.19
Themeda triandra	2	2.32	112.72	6.84	41.02
Oxalis perennans	1.67	1.54	2.32	4.56	45.58
Lepidosperma laterale	1.33	1.16	112.72	3.42	49
Macrozamia flexuosa	**1**	**1.16**	**112.72**	**3.42**	**52.42**
Corymbia maculata	2	1.15	0.58	3.39	55.81
Echinopogon ovatus	1.33	0.77	0.58	2.27	58.08
Eucalyptus punctata	1.67	0.77	0.58	2.27	60.36
Plantago debilis	1.33	0.77	0.58	2.27	62.63
Pratia purpurascens	1.33	0.77	0.58	2.27	64.91
Aristida ramosa	1.33	0.77	0.58	2.26	67.17
Brunoniella australis	1.33	0.77	0.58	2.26	69.43
Dichondra repens	1.33	0.77	0.58	2.26	71.69
Eucalyptus moluccana	1.67	0.77	0.58	2.26	73.95
Lepidosperma gunnii	1.67	0.77	0.58	2.26	76.21
Melichrus urceolatus	1.33	0.77	0.58	2.26	78.48
Notodanthonia longifolia	1.67	0.77	0.58	2.26	80.74
Olearia elliptica subsp. *elliptica*	1.33	0.77	0.58	2.26	83
Opercularia diphylla	0.67	0.39	0.58	1.15	84.15
Digitaria ramularis	1	0.39	0.58	1.14	85.29
Grevillea montana	0.67	0.39	0.58	1.14	86.42
Notelaea longifolia f. longifolia	1	0.39	0.58	1.14	87.56
Acacia parvipinnula	0.67	0.38	0.58	1.13	88.69
Aristida vagans	1	0.38	0.58	1.13	89.82
Breynia oblongifolia	0.67	0.38	0.58	1.13	90.95

Coastal Plains Smooth-barked Apple Woodland **(CPSAW)**

Average similarity: 35.19

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Themeda triandra	2.77	2.69	2.86	7.64	7.64
Entolasia stricta	2.69	2.37	1.87	6.75	14.39
Angophora costata	2.23	2.09	1.95	5.93	20.32
Corymbia gummifera	2.23	1.81	1.34	5.14	25.46
Panicum simile	1.85	1.71	1.5	4.85	30.31
Macrozamia flexuosa	**1.15**	**1.21**	**8.75**	**3.45**	**33.76**
Aristida vagans	1.62	1.16	0.89	3.3	37.06

Coastal Plains Smooth-barked Apple Woodland **(CPSAW)**

Average similarity: 35.19

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Billardiera scandens	1.31	1.14	1.85	3.25	40.3
Xanthorrhoea latifolia subsp. *latifolia*	1.62	1	0.72	2.85	43.15
Pteridium esculentum	1.62	0.99	0.85	2.82	45.97
Allocasuarina littoralis	1.77	0.97	0.62	2.76	48.73
Phyllanthus hirtellus	1.31	0.94	0.88	2.68	51.4
Lomandra obliqua	1.23	0.87	0.74	2.48	53.88
Glycine clandestina	1.15	0.81	1.04	2.3	56.18
Banksia collina	1.38	0.79	0.82	2.24	58.42
Imperata cylindrica	1.31	0.77	0.82	2.18	60.61
Gompholobium latifolium	1.08	0.68	0.83	1.93	62.54
Dianella caerulea var. *assera*	1	0.64	0.82	1.81	64.35
Persoonia linearis	0.92	0.59	0.89	1.69	66.03
Acacia myrtifolia	0.92	0.58	0.87	1.65	67.69
Lepidosperma laterale	1	0.57	0.58	1.62	69.31
Leptospermum trinervium	1.08	0.54	0.58	1.54	70.85
Ptilothrix deusta	1.08	0.51	0.55	1.44	72.29
Lambertia formosa	1.23	0.5	0.54	1.43	73.72
Eucalyptus piperita	1.38	0.49	0.42	1.39	75.11
Hardenbergia violacea	0.77	0.42	0.73	1.21	76.32
Gonocarpus tetragynus	0.85	0.42	0.56	1.19	77.5
Pimelea linifolia subsp. *linifolia*	0.85	0.4	0.56	1.13	78.63
Persoonia levis	0.69	0.34	0.58	0.95	79.59
Lomandra multiflora subsp. *multiflora*	0.77	0.33	0.46	0.95	80.54
Epacris pulchella	0.77	0.33	0.45	0.94	81.48
Eragrostis brownii	0.77	0.31	0.38	0.89	82.37
Leptospermum polygalifolium subsp. *cismontanum*	0.77	0.31	0.45	0.87	83.24
Eucalyptus capitellata	1	0.3	0.34	0.87	84.1
Anisopogon avenaceus	0.85	0.3	0.45	0.85	84.95
Patersonia glabrata	0.77	0.3	0.38	0.85	85.8
Pratia purpurascens	0.69	0.26	0.45	0.75	86.55
Dillwynia retorta	0.77	0.26	0.45	0.75	87.29
Microlaena stipoides var. *stipoides*	0.69	0.19	0.36	0.55	87.84
Eucalyptus umbra	0.85	0.19	0.25	0.55	88.39
Dodonaea triquetra	0.77	0.19	0.29	0.54	88.92
Rytidosperma pallidum	0.62	0.18	0.36	0.52	89.44
Brunoniella australis	0.62	0.18	0.29	0.51	89.95
Goodenia heterophylla subsp. *heterophylla*	0.54	0.16	0.36	0.46	90.41

Kurri Sands Swamp Woodland **(KSSW)**

Average similarity: 41.57

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Melaleuca nodosa	2.95	2.41	0.85	5.79	5.79
Lomandra cylindrica	1.81	2.35	2.05	5.64	11.44
Anisopogon avenaceus	1.9	2.2	2.25	5.3	16.74
Entolasia stricta	1.76	1.92	1.53	4.61	21.35
Dillwynia retorta	1.95	1.8	1.38	4.32	25.67
Macrozamia flexuosa	**1.24**	**1.48**	**4.88**	**3.56**	**29.24**
Astrotricha sp. Quorrobolong (S. Lewer 40)	1.52	1.47	1.36	3.55	32.78
Xanthorrhoea glauca subsp. *glauca*	1.52	1.41	1.3	3.4	36.18
Leptospermum parvifolium	1.81	1.28	0.74	3.09	39.27
Hakea sericea	1.52	1.17	0.86	2.81	42.08
Grevillea parviflora subsp. *parviflora*	1.38	1.12	0.91	2.68	44.76

Kurri Sands Swamp Woodland **(KSSW)**

Average similarity: 41.57

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Dianella revoluta var. *revoluta*	1.19	1.06	1.01	2.56	47.32
Eucalyptus parramattensis subsp. *decadens*	1.48	1.04	0.81	2.5	49.82
Aristida warburgii	1.33	1.04	0.76	2.5	52.32
Melaleuca thymifolia	1.33	1.02	0.79	2.47	54.78
Leucopogon virgatus	1.1	0.99	1.01	2.39	57.17
Platysace ericoides	1	0.82	0.91	1.97	59.14
Angophora bakeri	1.57	0.8	0.51	1.92	61.06
Pimelea linifolia subsp. *linifolia*	0.9	0.76	0.94	1.83	62.89
Isopogon anemonifolius	1.05	0.76	0.7	1.82	64.71
Eragrostis brownii	1.05	0.74	0.7	1.77	66.48
Hibbertia pedunculata	1	0.73	0.69	1.76	68.24
Leptospermum trinervium	1.1	0.66	0.67	1.58	69.82
Aristida ramosa	1.14	0.63	0.6	1.51	71.33
Themeda triandra	1.24	0.59	0.48	1.42	72.75
Lomandra glauca	1.05	0.55	0.49	1.32	74.07
Cassytha glabella f. glabella	0.86	0.55	0.62	1.32	75.39
Phyllanthus hirtellus	0.9	0.55	0.5	1.31	76.71
Cheilanthes sieberi subsp. *sieberi*	0.86	0.54	0.62	1.3	78.01
Monotoca scoparia	0.9	0.53	0.55	1.29	79.29
Callistemon linearis	0.9	0.53	0.45	1.27	80.56
Persoonia linearis	0.76	0.52	0.75	1.25	81.81
Banksia collina	1.05	0.51	0.48	1.23	83.04
Lepidosperma laterale	0.81	0.5	0.64	1.21	84.25
Grevillea montana	0.76	0.47	0.65	1.13	85.38
Bossiaea rhombifolia	1.14	0.41	0.39	0.99	86.37
Lambertia formosa	1	0.39	0.41	0.94	87.32
Eucalyptus fibrosa	0.62	0.37	0.59	0.89	88.21
Gonocarpus tetragynus	0.71	0.32	0.43	0.77	88.97
Acacia elongata	0.67	0.29	0.42	0.71	89.68
Acacia brownii	0.71	0.29	0.43	0.7	90.38

Lower Hunter Spotted Gum-Ironbark Forest Transition **(LHSGIF Transition)**

Average similarity: 43.97

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Entolasia stricta	2.71	3.05	5.28	6.94	6.94
Rytidosperma pallidum	2.43	2.93	3.46	6.66	13.6
Lomandra cylindrica	2	2.7	8.06	6.13	19.73
Pomax umbellata	2	2.7	8.06	6.13	25.86
Phyllanthus hirtellus	1.71	2.02	1.52	4.6	30.46
Corymbia maculata	1.86	1.98	2.84	4.49	34.96
Persoonia linearis	1.57	1.77	2.25	4.02	38.97
Eragrostis brownii	1.57	1.68	3.69	3.83	42.8
Grevillea parviflora subsp. *parviflora*	1.57	1.62	1.33	3.69	46.49
Leptospermum parvifolium	1.86	1.44	0.92	3.28	49.76
Macrozamia flexuosa	**1.29**	**1.43**	**3.19**	**3.24**	**53.01**
Lepidosperma laterale	1.43	1.38	1.3	3.14	56.15
Eucalyptus agglomerata	1.71	1.3	0.62	2.96	59.1
Hakea sericea	1.43	1.15	1.2	2.61	61.71
Platysace ericoides	1.29	1.13	0.86	2.56	64.27
Eucalyptus fibrosa	1.57	1.09	0.79	2.49	66.75
Melaleuca nodosa	1.57	0.88	0.79	1.99	68.75
Corymbia eximia	1.57	0.87	0.59	1.99	70.74

Lower Hunter Spotted Gum-Ironbark Forest Transition **Average similarity: 43.97**					**(LHSGIF Transition)**
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Astrotricha sp. Quorrobolong (S. Lewer 40)	1.14	0.79	0.85	1.79	72.52
Aristida ramosa	1.71	0.73	0.59	1.67	74.19
Monotoca scoparia	1	0.72	0.87	1.64	75.83
Anisopogon avenaceus	1.14	0.72	0.61	1.63	77.46
Cheilanthes sieberi subsp. *sieberi*	1.14	0.69	0.61	1.58	79.04
Grevillea montana	1	0.67	0.87	1.53	80.57
Cassytha glabella f. glabella	1	0.67	0.58	1.51	82.09
Gompholobium uncinatum	1	0.61	0.58	1.38	83.46
Daviesia ulicifolia	1.29	0.45	0.39	1.02	84.48
Goodenia rotundifolia	0.86	0.42	0.58	0.95	85.43
Acacia brownii	0.57	0.42	0.62	0.95	86.38
Podolobium ilicifolium	0.86	0.41	0.55	0.94	87.32
Melichrus urceolatus	0.71	0.39	0.61	0.9	88.22
Lomandra multiflora subsp. *multiflora*	0.71	0.38	0.61	0.87	89.09
Dillwynia retorta	1.14	0.37	0.4	0.85	89.93
Hardenbergia violacea	0.57	0.35	0.61	0.79	90.72

Hunter Valley Moist Forest **Average similarity: 33.57**					**(HVMF)**
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Corymbia maculata	3.33	2.63	1.27	7.83	7.83
Poa affinis	2.67	2.42	2.13	7.2	15.02
Entolasia stricta	2.17	1.9	1.26	5.65	20.67
Pteridium esculentum	2.33	1.74	2.86	5.18	25.85
Lomandra longifolia	1.83	1.62	1.36	4.83	30.69
Macrozamia flexuosa	**1.5**	**1.49**	**3.11**	**4.44**	**35.12**
Hardenbergia violacea	1	1.25	15.34	3.72	38.85
Themeda triandra	2	1.19	0.74	3.53	42.38
Dianella caerulea var. *assera*	1.33	1.06	1.17	3.16	45.54
Polyscias sambucifolia	1.33	1.05	1.19	3.14	48.68
Eustrephus latifolius	1.33	0.95	0.79	2.82	51.5
Breynia oblongifolia	1	0.82	1.36	2.44	53.94
Imperata cylindrica	1.67	0.81	0.69	2.43	56.36
Microlaena stipoides var. *stipoides*	1.17	0.74	0.72	2.19	58.55
Desmodium rhytidophyllum	1.17	0.73	0.74	2.17	60.73
Eucalyptus punctata	1.5	0.72	0.48	2.14	62.87
Dioscorea transversa	1.17	0.72	0.71	2.14	65.01
Eucalyptus acmenoides	1.67	0.71	0.48	2.11	67.12
Billardiera scandens	1	0.62	0.73	1.84	68.95
Pittosporum undulatum	1.17	0.58	0.73	1.72	70.67
Cassytha glabella f. glabella	1	0.57	0.71	1.7	72.37
Podolobium ilicifolium	1	0.5	0.48	1.49	73.86
Persoonia linearis	0.83	0.49	0.79	1.46	75.32
Eucalyptus umbra	1	0.49	0.48	1.45	76.76
Parsonsia straminea	0.83	0.47	0.79	1.41	78.17
Pandorea pandorana	1	0.46	0.48	1.37	79.54
Allocasuarina torulosa	1	0.32	0.45	0.97	80.5
Clematis glycinoides var. *glycinoides*	0.83	0.32	0.45	0.97	81.47
Notelaea longifolia f. longifolia	0.83	0.31	0.46	0.93	82.4
Oplismenus imbecillis	1	0.31	0.46	0.93	83.32
Pseuderanthemum variabile	0.83	0.31	0.46	0.93	84.25
Leucopogon lanceolatus var. *lanceolatus*	0.67	0.26	0.48	0.77	85.02

Hunter Valley Moist Forest **(HVMF)**

Average similarity: 33.57

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Myrsine variabilis	0.67	0.26	0.48	0.76	85.79
Angophora floribunda	1.17	0.25	0.26	0.76	86.55
Glochidion ferdinandi var. *ferdinandi*	0.67	0.25	0.48	0.75	87.3
Zieria smithii	0.5	0.25	0.48	0.75	88.05
Denhamia silvestris	0.5	0.25	0.48	0.74	88.79
Glycine clandestina	0.67	0.25	0.48	0.73	89.53
Geitonoplesium cymosum	0.5	0.23	0.48	0.68	90.21

Coastal Plains Scribbly Gum Woodland **(CPSGW)**

Average similarity: 35.90

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Dillwynia retorta	3	3.85	-	10.71	10.71
Drosera auriculata	2	2.56	-	7.14	17.86
Entolasia stricta	2.5	2.56	-	7.14	25
Epacris pulchella	2	2.56	-	7.14	32.14
Eucalyptus haemastoma	3	2.56	-	7.14	39.29
Lindsaea linearis	2	2.56	-	7.14	46.43
Platysace linearifolia	2	2.56	-	7.14	53.57
Tetratheca juncea	2.5	2.56	-	7.14	60.71
Acacia suaveolens	1.5	1.28	-	3.57	64.29
Acacia ulicifolia	1.5	1.28	-	3.57	67.86
Banksia oblongifolia	1.5	1.28	-	3.57	71.43
Cassytha glabella f. glabella	1.5	1.28	-	3.57	75
Corymbia gummifera	2	1.28	-	3.57	78.57
Dampiera stricta	1.5	1.28	-	3.57	82.14
Dianella caerulea var. *assera*	1.5	1.28	-	3.57	85.71
Mirbelia rubiifolia	1.5	1.28	-	3.57	89.29
Persoonia levis	1	1.28	-	3.57	92.86

Seaham Spotted Gum-Ironbark Forest **(SSGIF)**

Average similarity: 43.83

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Microlaena stipoides var. *stipoides*	2.5	2.06	4.73	4.69	4.69
Dichondra repens	2	1.89	44.34	4.32	9.01
Pratia purpurascens	2	1.89	44.34	4.32	13.32
Corymbia maculata	2.5	1.88	1.86	4.29	17.61
Eucalyptus acmenoides	2.5	1.43	0.91	3.27	20.88
Brunoniella australis	1.75	1.43	2.64	3.25	24.14
Galium binifolium	1.75	1.41	2.82	3.22	27.36
Notelaea longifolia f. longifolia	1.75	1.11	2.66	2.53	29.89
Acacia implexa	1.5	1.1	2.84	2.52	32.41
Oxalis perennans	1.5	1.1	2.84	2.52	34.93
Cheilanthes sieberi subsp. *sieberi*	1.5	1.1	3.08	2.51	37.43
Desmodium gunnii	1.5	0.96	0.91	2.19	39.62
Dianella caerulea var. *assera*	1.5	0.96	0.91	2.19	41.81
Glycine clandestina	1.5	0.96	0.91	2.19	44
Panicum simile	1.5	0.96	0.91	2.19	46.18
Poa labillardierei var. *labillardierei*	1.5	0.96	0.91	2.19	48.37
Allocasuarina torulosa	1.75	0.96	0.91	2.18	50.55
Oplismenus imbecillis	1.75	0.96	0.91	2.18	52.73
Breynia oblongifolia	1.25	0.95	44.34	2.16	54.89

Seaham Spotted Gum-Ironbark Forest **(SSGIF)**
Average similarity: 43.83

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Desmodium rhytidophyllum	1.25	0.95	44.34	2.16	57.05
Eustrephus latifolius	1	0.95	44.34	2.16	59.21
Lomandra longifolia	1.25	0.95	44.34	2.16	61.36
Macrozamia flexuosa	**1.25**	**0.95**	**44.34**	**2.16**	**63.52**
Denhamia silvestris	1.25	0.95	44.34	2.16	65.68
Myrsine variabilis	1.25	0.95	44.34	2.16	67.84
Dichelachne micrantha	1.5	0.93	0.91	2.13	69.97
Plantago debilis	1.5	0.93	0.91	2.13	72.1
Leucopogon juniperinus	1.5	0.64	0.81	1.47	73.57
Lagenophora stipitata	1.25	0.64	0.81	1.46	75.03
Lomandra multiflora subsp. *multiflora*	1.25	0.64	0.82	1.45	76.49
Echinopogon ovatus	1.25	0.64	0.82	1.45	77.94
Imperata cylindrica	1.5	0.64	0.82	1.45	79.39
Veronica plebeia	1.25	0.64	0.82	1.45	80.83
Plectranthus parviflorus	1.25	0.62	0.81	1.43	82.26
Eucalyptus siderophloia	1.75	0.49	0.41	1.12	83.38
Clematicissus opaca	0.75	0.48	0.91	1.09	84.47
Pomax umbellata	0.75	0.48	0.91	1.09	85.57
Clerodendrum tomentosum	0.75	0.48	0.91	1.09	86.66
Geitonoplesium cymosum	1	0.47	0.91	1.07	87.72
Lepidosperma laterale	1	0.47	0.91	1.07	88.79
Sigesbeckia orientalis subsp. *orientalis*	0.75	0.47	0.91	1.07	89.85
Vernonia cinerea var. *cinerea*	1	0.47	0.91	1.07	90.92

Appendix 2 IUCN Conservation Risk Assessment for *Macrozamia flexuosa*

A conservation risk assessment for *Macrozamia flexuosa*, using IUCN (2017) criteria, has been undertaken with the best available information. Key factors in the application of the five IUCN assessment categories are the extent of occurrence, occupancy area, population size and dynamics, and generational time. Data on all of these factors are not essential for an assessment to proceed, as a listing for Critically Endangered, Endangered or Vulnerable can be triggered through multiple paths.

Extent of Occurrence (Criteria A & B) - Based on all available and valid point locations for *Macrozamia flexuosa* (n=582), the extent of occurrence (EOO) has been calculated as 6,319 km^2 (631,900 ha) using the online Geospatial Conservation Assessment Tool (GeoCAT: https://www.kew.org/science/projects/geocat-%E2%80%93-geospatial-conservation-assessment-tool). Six records were excluded from this analysis, as detailed earlier in this paper. Of these, five are observation records only with no voucher specimens in support, which lessens their reliability. Juvenile individuals of *Macrozamia reducta* K.D.Hill & D.L.Jones and *Macrozamia communis* do occasionally exhibit a flexuous habitat, and it is possible that these have been misidentified as *Macrozamia flexuosa*. Alternatively, these individuals may instead refer to *Macrozamia spiralis*, a predominantly Sydney-based species that also supports a twisted leaf rachis. The sixth excluded record is an AVH collection from 1881 '*near Port Jackson*', which within the context of European colonisation at that time may refer to any location between Sydney and the Hunter region. If all 588 records are accepted as valid, the EOO increases significantly to 20,736 km^2. Hill (2010) had earlier estimated EOO as 3,500 km^2, nearly half of that determined from point data records (excluding outliers) here.

Area of Occupancy (Criteria A, B & D) – the IUCN Guidelines suggest that a scale of 1-4 km^2 is generally appropriate for assessing occupancy area for most species. Consequently, using a cell size of 4 km^2, again using GeoCAT, an area of occupancy (AOO) of 696 km^2 (69,600 ha) was determined for the 582 valid point locations (excluding the 6 outliers). With all records retained, the AOO is marginally greater at 720 km^2.

Population Size (Criteria A, C & D) - To date, no comprehensive detailed studies on population size of *Macrozamia flexuosa* have yet been undertaken, although Hill (2010) estimated a range of between 2,500 to 10,000 mature individuals. As a surrogate, it is possible to extrapolate this number based on field and herbarium specimen notes, and the application of cover abundance values when sampled during vegetation classification exercises. For the 86 full floristic 0.04 ha sample plots analysed in this study, estimates of cover abundance values used the modified Braun-Blanquet (1928) scale (1 = <5% cover, few individuals; 2 = <5% cover, many individuals; 3 = 6-25% cover; 4 = 26-50% cover; 5 = 51-75% cover; 6 = 76-100% cover). For practical applications when applying cover values of 1 or 2 in the field, the word 'few' generally translates as 5 individuals or less, and 'many' as greater than 5 individuals (but covering only up to 5% or 20 m^2 of the plot). Within a 20m^2 area and based on field observations, it may be expected that a maximum of 20-25 mature individuals of *Macrozamia flexuosa* can be present. For a cover value of 3 (6-25% cover under the Braun-Blanquet scale), perhaps 25-150 mature individuals may be present. Of the 86 sample plots available, 72% recorded *Macrozamia flexuosa* with a cover value of 1 (1-5 individuals/0.04 ha, or 25-125 individuals/ha), 27% with a cover value of 2 (6-25 individuals/0.04 ha, or 150-625 individuals/ha), and 1% with a cover value of 3 (26-150 individuals/0.04 ha, or 650-3,750 individuals/ha). As none of the 86 floristic plots were positioned to specifically target *Macrozamia flexuosa*, they can be considered to represent a random sample of occupied habitat. Overwhelmingly, this species occurs only sparingly within sampled habitat, with 99% of plots recording 1 to 25 mature individuals in a 0.04 ha plot, or 25 to 625 mature individuals per hectare. By comparison, quantitative assessments by Preece et al (2007) for *Macrozamia macdonnellii*, Binns and Meek (2008) for *Macrozamia johnsonii*, Terry et al (2008) for *Macrozamia platyrhachis* and Hall and Walter (2013) for *Macrozamia miquelii* resulted in densities of 50-100, 158, 700-4,575 and 1,000-4,600 mature individuals per hectare respectively.

Extrapolating these figures for *Macrozamia flexuosa* density across the regional extent of occurrence (i.e. 25-625 individuals/ha over 631,900 ha), the maximum expected population size (assuming that all habitat within this area is suitable and supports the species) is likely to lie somewhere between 15,797,500 and 394,937,500 individuals. This estimate is comparable to recent work undertaken on *Macrozamia johnsonii* by Binns & Meek (2008), who calculated approximately 3,500,000 plants over an extent of occurrence of only 22,200 ha (an area c. 3.5% of the extent of occurrence of *Macrozamia flexuosa*). However, based on the current as-known area of occupancy for *Macrozamia flexuosa* (69,600 ha) a total population of between 1,740,000 and 43,500,000 individuals is more realistic. This estimate is comparable to that calculated in other studies: Terry et al (2008) estimated over 611,000 adult plants of *Macrozamia platyrhachis* in central Queensland, but within a total occupancy area of only 365 ha (c. 0.5% of the occupancy area of *Macrozamia flexuosa*).

Plant Generation (Criteria A, C & E) – the issue of generational time is important in some assessment criteria, and the IUCN Guidelines define this as '*the average age of parents of the current cohort (i.e. newborn individuals in the population)*', and '*generation length is greater than the age at first breeding and less than the age of the oldest breeding individual*'. As with most *Macrozamia*, the life span of *Macrozamia flexuosa* can extend for several decades, and potentially over one hundred years. Benson and McDougall (1993) and Hill (2010) suggested longevity in this species to be 60 years or more, and for the related *Macrozamia communis* and *Macrozamia spiralis* they specify a primary juvenile period (time to first reproduction) of 10-20 years. Binns and Meek (2008) consider *Macrozamia johnsonii* to have very low natural mortality and an unspecified yet long generation time, with a primary juvenile period of 20-40 years. Preece et al (2007) suggested that some individuals of *Macrozamia macdonnellii* may be several centuries old, and for *Macrozamia platyrhachis* Terry et al (2008) estimated a generation time of 20-25 years (60-80 years for three generations). In the absence of suitable quantitative data, figures such as these are also plausible for *Macrozamia flexuosa*, and for IUCN assessments a 20 year generation period has been selected.

Reduction in Population (Criterion A) – the IUCN Guidelines specify a reducing population as one which shows '*a decline in the number of mature individuals of at least the amount (%) stated under the criterion over the time period (years) specified, although the decline need not be continuing*'. The causes of decline are separated into those that are reversible (e.g. changing land management practices), those that are irreversible (e.g. land clearing), those that are fully understood (e.g. fire regime) and those that have now ceased (e.g. collecting). For *Macrozamia flexuosa*, the greatest threat known to result in declining populations is land clearing, which is irreversible and continuing.

Using available data, and incorporating the qualifying statements made above, the following IUCN assessment has been made for *Macrozamia flexuosa*.

- **Criterion A: Reduction in population size**: Under Red List definitions, population is the total number of individuals of a taxon, which for functional reasons is measured as the number of mature individuals only. A reduction in population size is assessed over a 10-year period or three generations of the target taxon (whichever is greater): in the case of *Macrozamia flexuosa*, three generations is estimated to be at least 60 years. Based on current knowledge, an estimated extant population size of 1,740,000 and 43,500,000 mature individuals has been calculated for *Macrozamia flexuosa*. There is no comprehensive data on historical population sizes, and consequently it is difficult to quantify the reduction that may have occurred over the preceding 60 years. With the amount of land clearing that has been undertaken in the lower Hunter over the past 100 years, a reduction in population size is certainly likely. However, it is doubtful that this reduction would be greater than 30% over the last 60 years (since 1955). Ongoing clearing will potentially further reduce the number of extant plants, but it is not expected that this will exceed 30% over the next 60 years. Potential limitations in pollination and dispersal for this species (see Discussion above) may influence the triggering of a reduction in population size over three generations, however there is insufficient data at present to quantify this trend. Populations may very well be static and therefore not show any decreasing trends over a 60-year period.

  Macrozamia flexuosa does not meet the various sub-criteria for Critically Endangered (inferred, non-reversible population reduction ≥ 80%, past or future), Endangered (inferred, non-reversible population reduction ≥ 50%, past or future) or Vulnerable (inferred, non-reversible population reduction ≥ 30%, past or future) under Criterion A.

- **Criterion B: Geographical Range (B1, extent of occurrence and/or B2, area of occupancy):** The extent of occurrence (Criterion B1) for *Macrozamia flexuosa* has been estimated at 6,319 km^2. This figure exceeds the thresholds for Critically Endangered (<100 km^2) and Endangered (<5,000 km^2), but meets the threshold for Vulnerable (<20,000 km^2). However, for Criterion B1 to be enacted two of three sub-criteria must also be met. The first of these (severely fragmented population or known to exist at <10 locations) does not apply given the 588 point records of this species dispersed over a wide area. IUCN guidelines define location as a '*geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present*'. The 588 point locations occupy a wide range of habitats subject to many potentially threatening events, and it is estimated that at least 25 'locations' are definable under this definition. In addition, 'severely fragmented' refers to a situation where most individuals are found in small and relatively isolated subpopulations, with a reduced probability of gene flow and recolonization if they become locally extinct. While the distribution of *Macrozamia flexuosa* may be sparse at most locations, subpopulations are not small or isolated in this sense. The second sub-criteria relates to an observed, inferred or projected and continuing decline, which for *Macrozamia flexuosa* is likely to be met with continuing habitat loss. The final sub-criterion considers extreme fluctuations in extent of occurrence, area of occupancy, number of locations of subpopulations or number of mature individuals. Apart from declines in some of these attributes, there are unlikely to be any extreme fluctuations in *Macrozamia flexuosa* populations, as this species is a stable and long-lived taxon.

  The area of occupancy (Criterion B2) for *Macrozamia flexuosa* has been estimated at 696 km^2. This is outside of the threshold for Critically Endangered (<10 km^2) and Endangered (<500 km^2) but meets the threshold for Vulnerable (<2,000 km^2). However, as with extent of occurrence, for Criterion B2 to be enacted two of the same three sub-criteria outlined above must also be met. As discussed above, these sub-criteria are not fulfilled, and hence neither Criteria B1 nor Criteria B2 apply to *Macrozamia flexuosa*.

- **Criterion C: Population Size:** Best estimates for the total (regional) population size of *Macrozamia flexuosa* are between 1,740,000 and 43,500,000 individuals. In the absence of quantitative data within replicated sample areas, this is based on an extrapolation of plot-based cover abundance data across the calculated area of occupancy for this species. Recognising the limitations of this method, the lower bounds of this estimate clearly exceed the thresholds for Critically Endangered (<250 mature individuals), Endangered (<2,500 mature individuals) and Vulnerable (<10,000 mature individuals), and Criterion C (or any of the sub-criteria within) does not apply to *Macrozamia flexuosa*.

- **Criterion D: Very Small Population Size:** As for Criterion C, the lower estimate of over 1,740,000 mature individuals of *Macrozamia flexuosa* clearly exceeds the threshold for Critically Endangered (<50 mature individuals), Endangered (<250 mature individuals) and Vulnerable (D1: <1,000 mature individuals; or D2: area of occupancy <20 km^2, <5 locations), and Criterion D does not apply.
- **Criterion E: Quantitative Analysis:** The IUCN guidelines specify quantitative analysis as being any form of analysis (such as population viability analysis) which estimates the extinction probability of a taxon based on known life history, habitat requirements, threats and any specified management options. At present, insufficient data is available on life history and threats to *Macrozamia flexuosa* to enable a quantitative analysis to be undertaken, and hence Criterion E is not applicable.

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Letters from Thomas Reedy to Sir William Macarthur, during the Chevert Expedition of 1875

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***Abstract*:** Thomas Reedy (1842-1929) was head gardener for Sir William Macarthur. In 1875, as an expeditionary member on the Chevert Expedition, he collected plants from islands in the Great Barrier Reef, the Torres Strait and New Guinea for Macarthur. Three surviving letters to his employer, Sir William Macarthur, are introduced, transcribed and minimally annotated.

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Introduction

In 1875, Sir William Macleay financed and led a scientific expedition to New Guinea; the first scientific expedition from Australia to a foreign shore (Fulton 2012). The expedition was considered enormously successful in scientific circles obtaining roughly 1,000 birds, 800 fish, many reptiles, mammals, insects, spiders, marine molluscs and ethnographic objects (Macleay 1875a; Fulton 2012; 2016a; 2018). The expedition is commonly referred to as the Chevert expedition following the name of the ship *Chevert* that carried the expeditioners (Fulton and Bialek 2018). There were also three plant collectors sent by Sir William Macarthur. Thomas Reedy was the most senior of these three and was the head gardener at *Camden Park*, the family estate of the Macarthurs southwest of Sydney. He had worked at *Camden Park* since 1854, retiring in 1926 (Fulton 2016b). Reedy collected assiduously and was mentioned several times by Sir William Macleay in his personal journal of the expedition (Macleay 1875b). Reedy and the other plant collectors collected 800-1000 living plants, in addition to an unknown number of seeds, and at least 157 dried specimens, the latter were sent to Baron Ferdinand von Mueller, in Melbourne (Macarthur 1875; Fulton 2016b).

The zoology and anthropology of the Chevert expedition have been frequently discussed in the literature (e.g. Fletcher 1893; 1929; Ramsay 1877; Fulton 2001; 2016b; 2012 and references therein; 2017a; 2017b; Davies 2007) while Reedy's botanical collections have been comparatively ignored. This lack of reporting surely stems from the dearth of reference material available to researchers. Beyond Mueller's Descriptive Notes on Papuan Plants I (Mueller 1875) and the recent publication of dried specimens collected by Reedy on the expedition (Fulton 2016b) and John Dowe's report on Macarthur's Palm *Ptychosperma macarthurii* (H.Wendl. ex H.J.Veitch) H.Wendl. ex Hook.f. (Dowe 2007), there is little to report and less to discuss.

However, three hand-written letters by Thomas Reedy were detected in the archives of the Mitchell Library, in Sydney. All three were addressed to Reedy's employer Sir William Macarthur and reported some of Reedy's collections along with minor ecological notes. The first two letters were addressed from the "Ship Chevert" and dated May 30, 1875 and June 12, 1875; they briefly discussed Reedy's collecting efforts on islands in the Great Barrier Reef. The third was sent from "Somerset", which was the final government outpost near the tip of Cape York and dated June 25, 1875. This letter provided more commentary with Reedy thinking of matters at home and promising to make good inventory of what will soon be collected in New Guinea. It also welcomes the fresh goods sent by Macarthur to the expeditioners, which arrived by the mail steamer at Somerset. These letters carry minimal information on the plants collected, but report some sense of Reedy's feelings and thoughts at the time. In all letters, Reedy sounds enthusiastic about what he has collected and seen. The letters provide a little more information on what was collected—where and when. Yet surely their greatest value lies in reporting the thoughts, feelings and emotions of one of the lesser known and less famous members of the expedition. Such letters add a human context to what would otherwise be merely botanical and historical data.

The letters have been carefully transcribed below. They are annotated with current species names following the Australian Plant Census (APC), and where appropriate annotated with concise commentary and references. Additions and changes to Reedy's letters are placed within square brackets, although some minor and punctuation changes have been incorporated to improve the overall readability of the letters. Copies of Thomas Reedy's original handwritten letters are given as Appendix 1, because his handwriting may convey a sense of emotion through inflections that type cannot. The original letters may also be read and interpreted contrarily by different researchers.

The Letters

Ship Chevert

May 30th 75

My dear Sir William we have had a very pleasant passage up to this time and I have not been sea sick. We are all of us very comfortable and well provided for. Mr Macleay is kind to us. We went ashore on Friday at Percy Island No. 2, the vegetation on that island and the surrounding islands are very poor. I found a terrestrial orchid, which I think is new. I got 2 plants of it, the flower stem is from 12 to 18 inches in height and from 20 to 30 flowers on the stem, thick fleshy tubers about the size of a man's finger. I gave Capt. Onslow a flower to send you. I hope things are going on well at Camden.

I am, dear Sir William, your humble Servant Thomas Reedy.

Ship Chevert

June 12th 75

My dear Sir William we called at several of the islands as we came along but did not go on to the mainland, which I am sorry for as I think there would be some things to be had. Most of the islands are full of *Dendrobium undulatum* [*Durabaculum undulatum* (R.Br.) M.A.Clem. & D.L.Jones; *Dendrobium undulatum* R.Br. is an illegitimate name. Various varieties have been named in the genus *Durabaculum* (Clements & Jones 2002)] some of the plants from 4 to 6 feet in height – the vegetation on those islands are nearly alike. I got some few seeds of different things and also some plants for drying, which I find very difficult to dry at sea more so when the days are damp. I have packed 3 casks and 1 close[d] box with plants which I hope the mail steamer will take tomorrow as we are going to meet it on our way with the steam launch. I have not labelled the plants but I keep a memo of them. The small casks are filled with a dendrobium from Barrow Island. This is a lovely orchid something like *Dendrobium monanthum* [*Dendrobium monanthum* Teijsm. & Binn. (from IPNI 2019): here Reedy refers to a plant, which is not native to Australia.] in colour and size of flower except much stronger in growth and several flower spikes a stem, from 12 to 20 flowers on the stem, it looks charming in flower. I got all I could of it. I should liked to have got more but we did not stay long at that island. It is found on the bare rocks exposed to much heat and dryness, it is possible that it may be *Dendrobium bigibbum* [*Vappodes bigibba* (Lindl. & Paxton) M.A.Clem. & D.L.Jones], but I cannot say for certain [A dried specimen of this species from Cape Grenville, collected by Reedy, is in the National Herbarium of Victoria MEL 624057A (Fulton 2016b, p 61)]. The large cask contains *Dendrobium undulatum* [*Durabaculum undulatum* (R.Br.) M.A.Clem. & D.L.Jones] and *Bolbophyllum* sp. [orthographic variant of *Bulbophyllum* Thouars nom. cons.] from Fitzroy Island and a few of the dendrobium from Barrow Island. I daresay you will not care for *D. undulatum* nor the *Bolbophyllum* but I thought they would do for exchange with some of the people at Sydney. The close[d] box contains *Drynaria quercifolia* [*Drynaria quercifolia* (L.) J.Sm.] and —— large variety very handsome in growth and also a small fern which I have seen before. *Bletia* [*Bletia* is a genus in Orchidaceae] from Palm Island growing in black soil and much shaded this I [have] not seen before. Terrestrial orchid from Percy Island this is very pretty indeed and some plants growing on the *Acrostichum grande* [the fern, *Platycerium superbum* de Jonch. & Hennipman.], which I do not know. Please to have the casks opened on the end that the label is on; one cannot pack plants on board ship the same as on land but I hope they will reach you safe.

Somerset

June 25th 75

Dear Sir William

I have just received your kind letters it has given me great pleasure to hear from you, at the same time I am very sorry that you should have had so much trouble with the tank and that there has been another flood at Camden. I have not read all your letters as we start early tomorrow for New Guinea. I shall keep account of every thing that I get at New Guinea. I am happy to hear that Sir George Macleay is taking such interest in getting plants for you sir and also to hear that Mr Stephens has not forgotten you altogether. I did not sow all the seed of *Kentia wendlandiana* [*Hydriastele wendlandiana* (F.Muell.) H.Wendl. & Drude] it is to be found on the loft in a brandy case in the shed packed with light soil, the seeds may not be good as they are a long time exposed. I shall send you account of every thing that I get at New Guinea should I get a chance to do so, we have just landed the oranges [& etc] they will be most acceptable. I enclose a flower of dendrobium from Cape York it is not dry but you may have a chance to see it. I hope to be able to dry this flower. I have sent you a lot of plants of it [A dried specimen of *Dendrobium rigidum* R.Br., collected by Reedy from near Somerset, is in the National Herbarium of Victoria MEL 624409A (Fulton 2016b, p 61)]. I am very glad that Mr Sanderson devotes so much of his time at Camden Park. I trust by the time of our arrival at Camden at least my home that you Sir William will have a fine lot of plants from England and that we shall bring with us a fine collection of things from New Guinea for you sir. I shall take care of myself with the help of God. I thank you for your kindness in looking after my wife and family. I wish you good bye Sir William.

Yours most obediently

Thomas Reedy.

I miss you very much Sir.

Acknowledgements

We thank Neville Walsh for his advice on nomenclature with regard to orchids and an anonymous referee who commented on the submitted manuscript.

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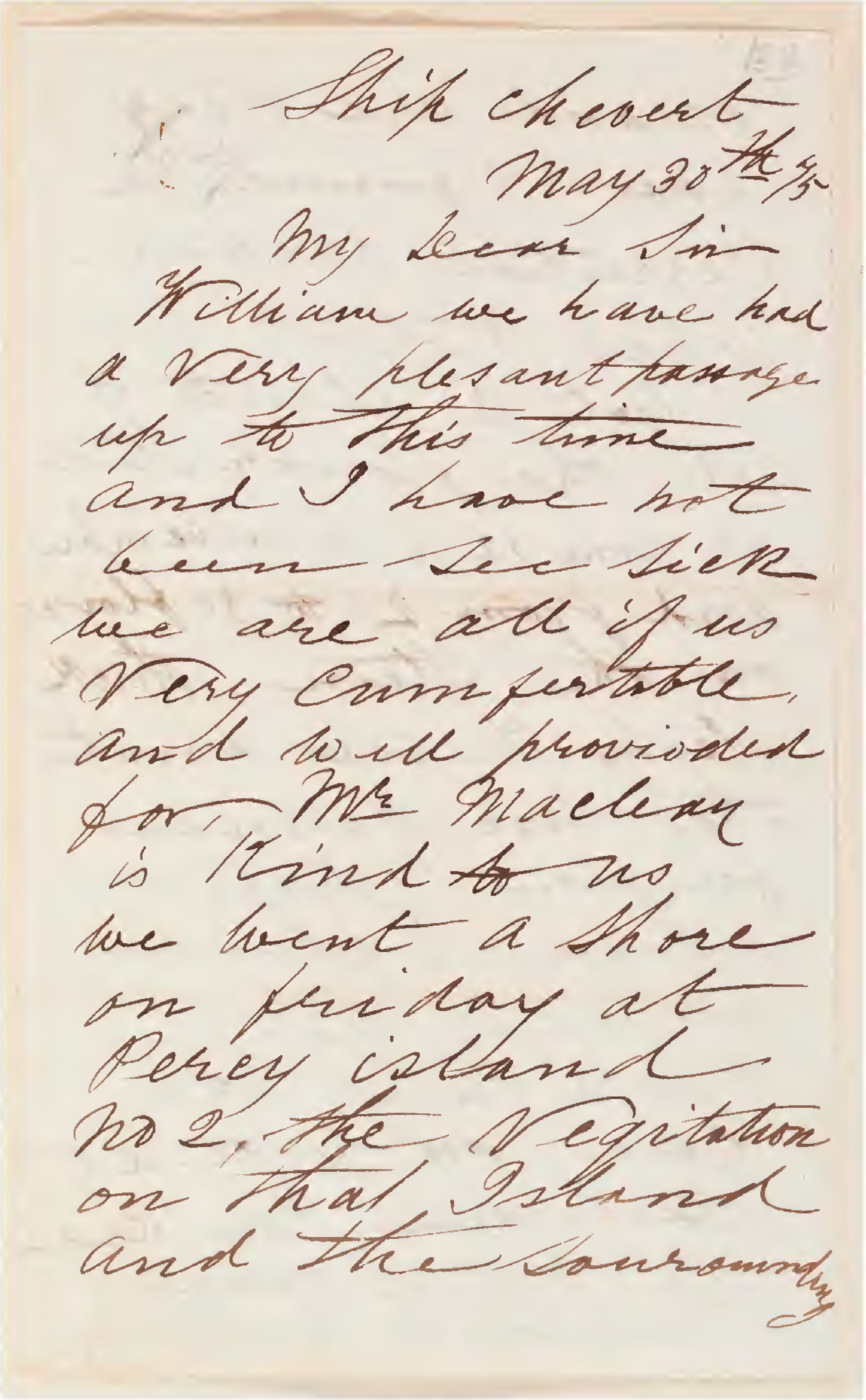
Manuscript accepted 17 March 2019

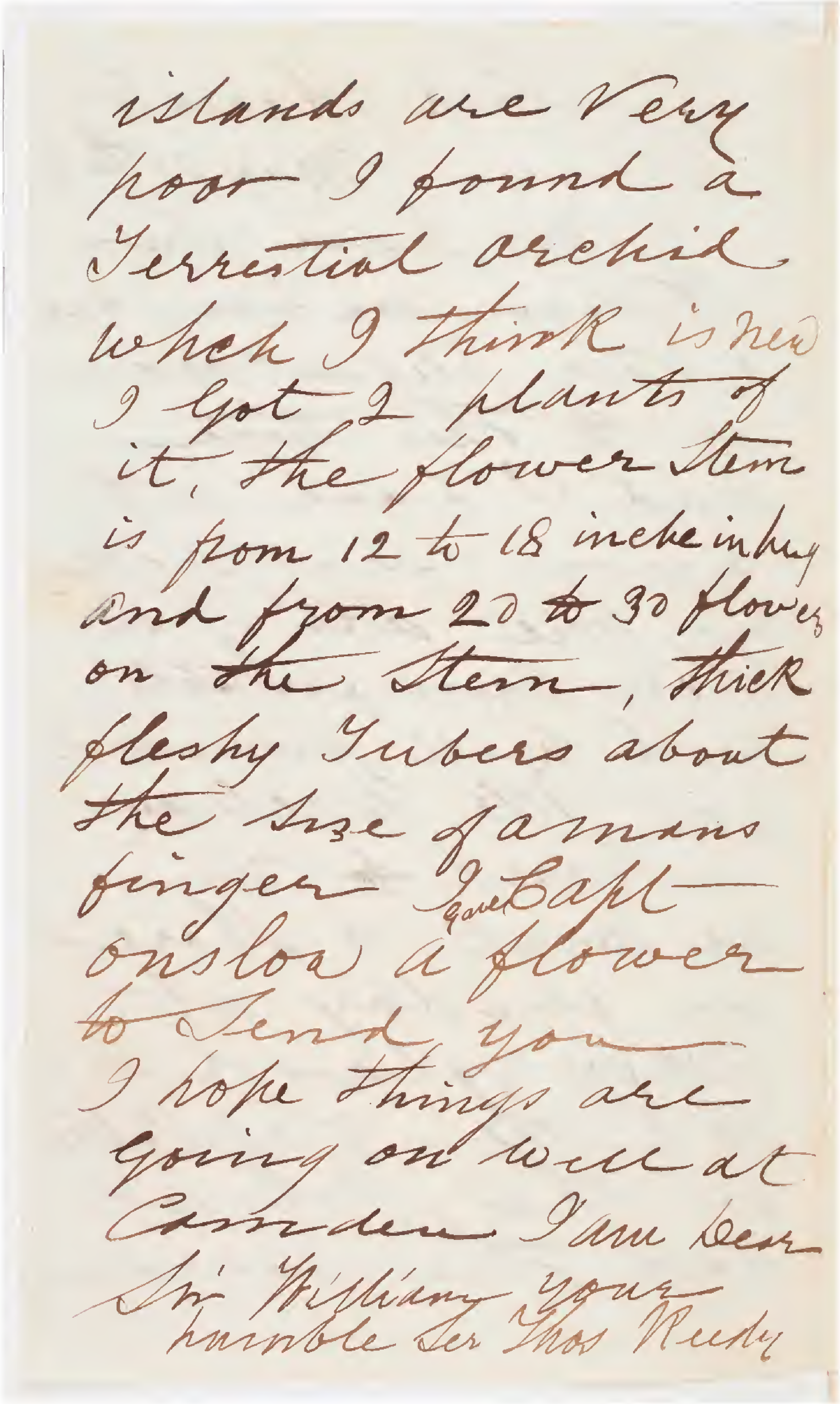
APPENDIX 1

Thomas Reedy's Letters to Sir William Macarthur – copies of the original letters (Reedy 1875)

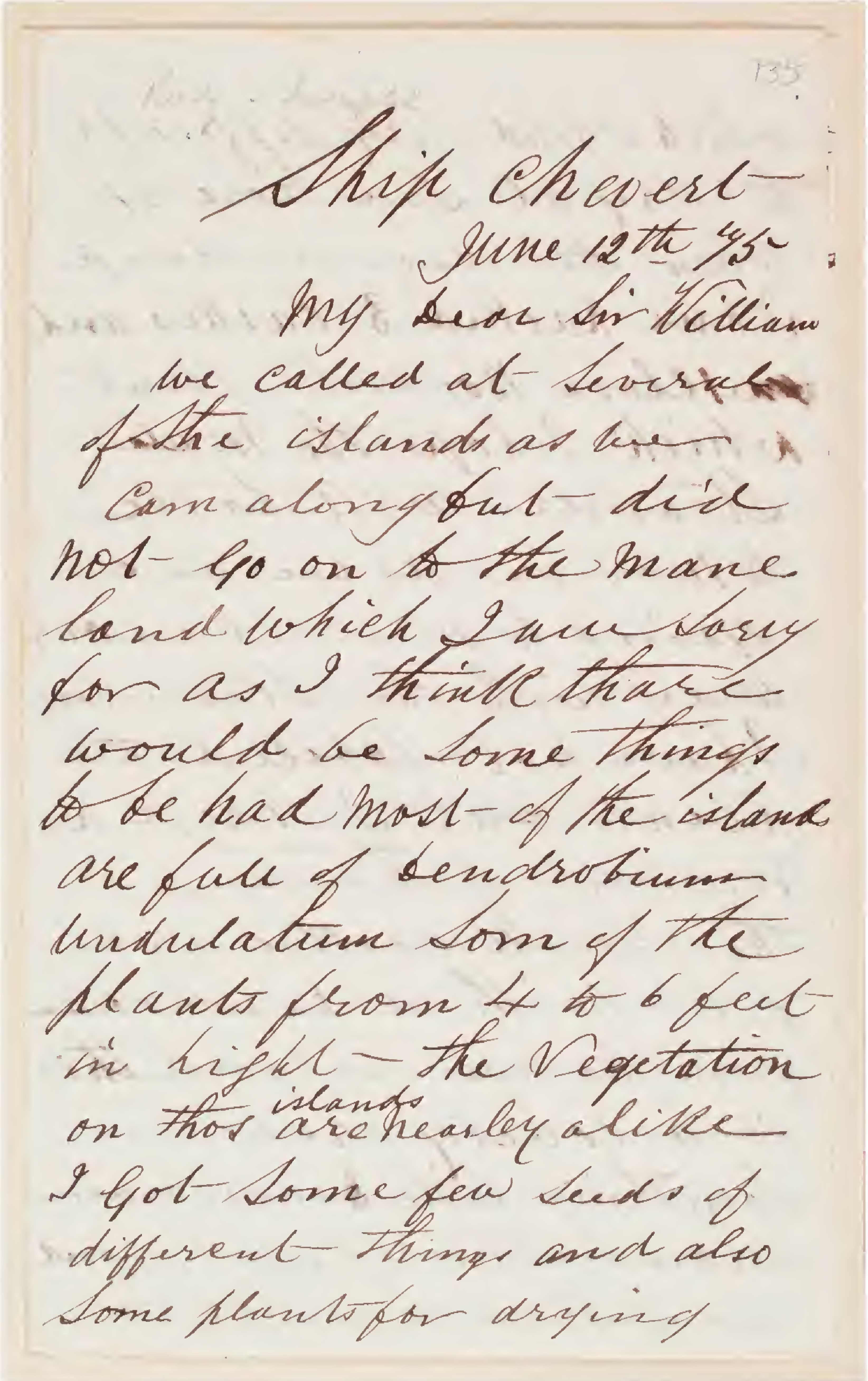
(State Library of New South Wales- Call Number A 2939 (CY 1004). Frame numbers 120-126).



Ship Chevert
May 30th 75
My Dear Sir
William we have had
a Very plesant passage
up to this time
and I have not
been see sick
we are all of us
Very Cumfortable,
and well provided
for, Mr Macleay
is Kind to us
we went a Shore
on friday at
Percy island
No 2, the Vegitation
on that Island
and the Sourounding



islands are Very
poor I found a
Terrestial orchid
which I think is new
I Got 2 plants of
it, the flower Stem
is from 12 to 18 inche in leng
and from 20 to 30 flowers
on the Stem, thick
fleshy Tubers about
the size of a mans
finger I gave Capt
onsloa a flower
to send you
I hope things are
Going on well at
Camden I am Dear
Sir William your
humble Ser Thos Reedy

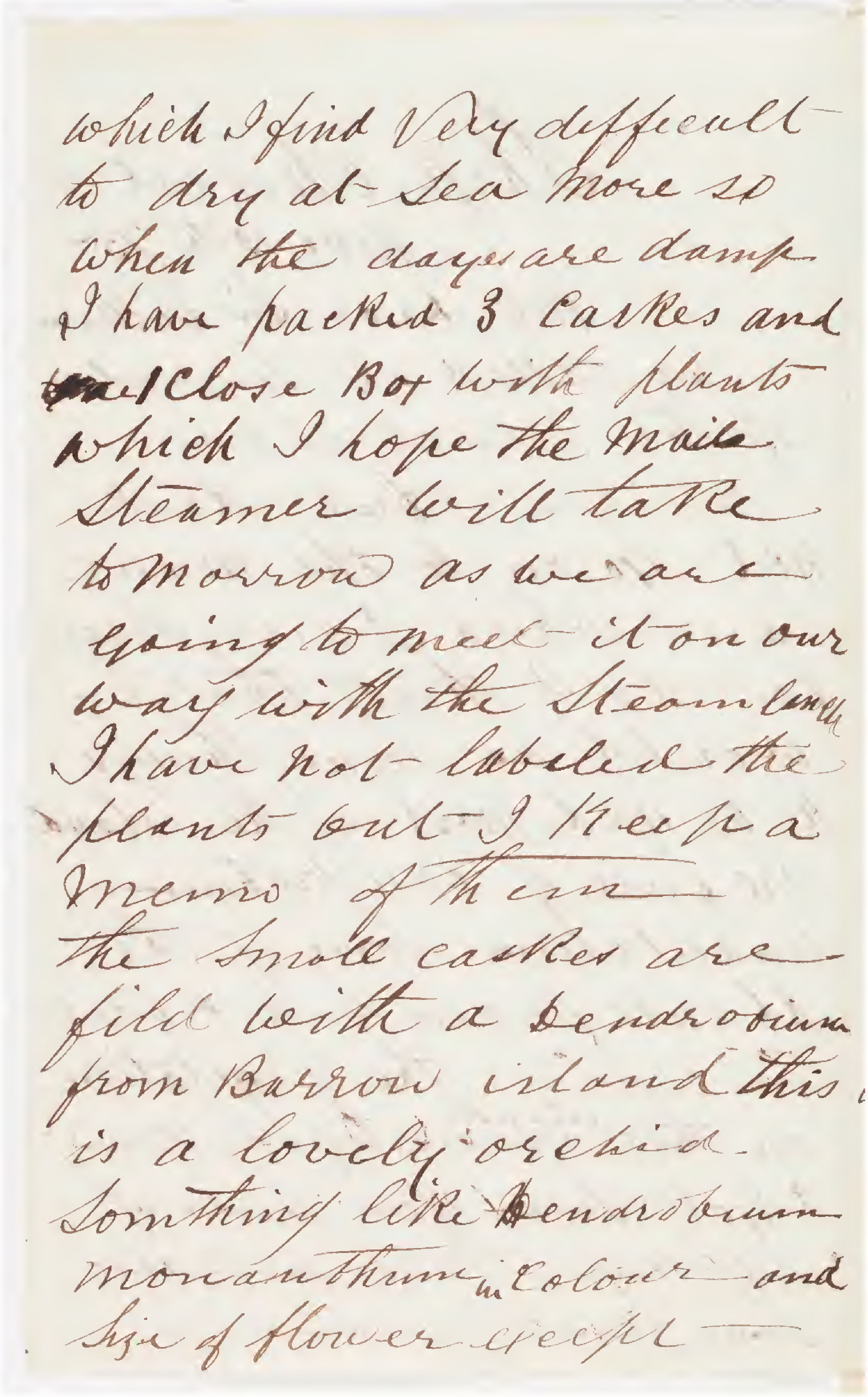


135

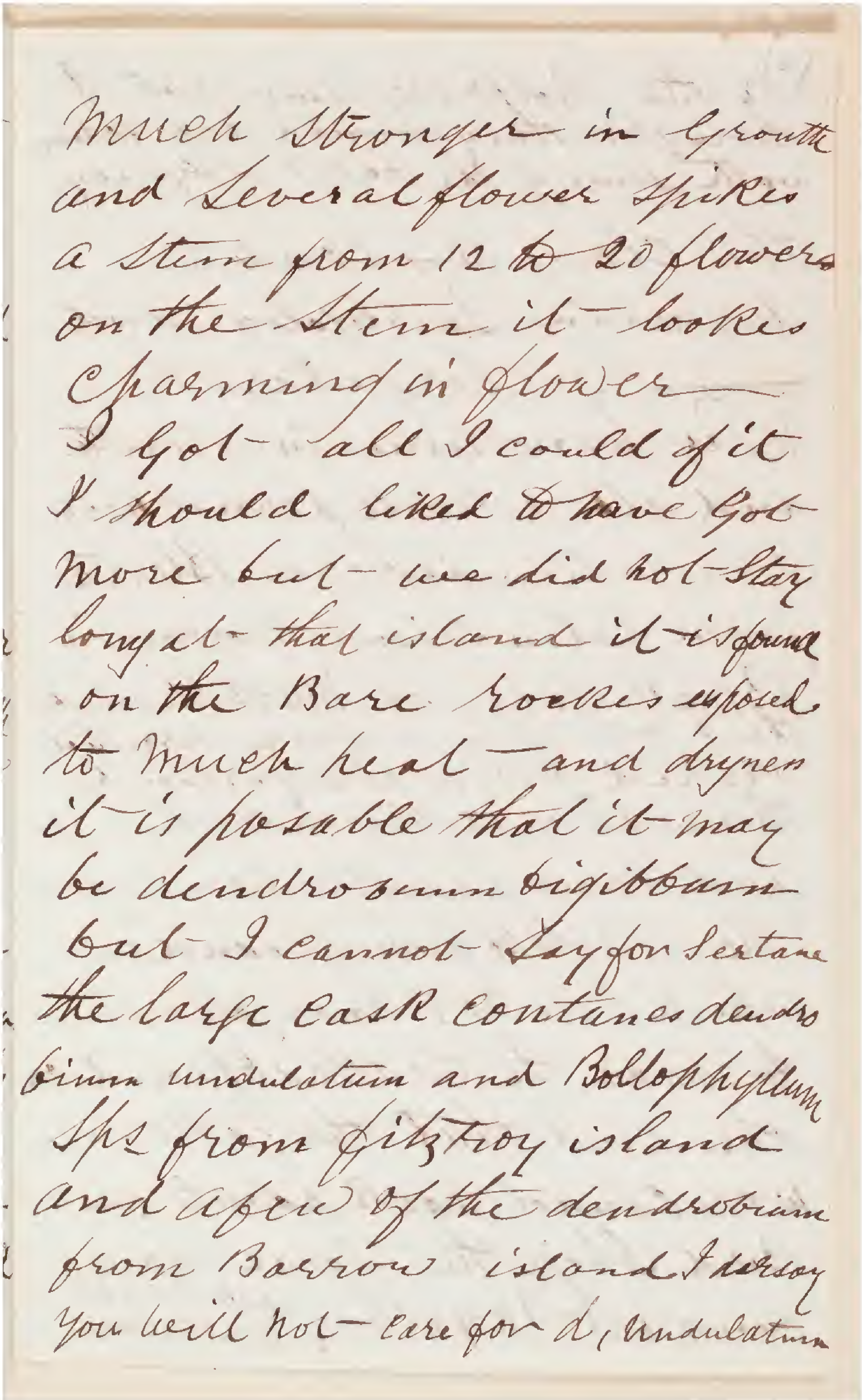
Ship Chevert
June 12th 75

My Dear Sir William

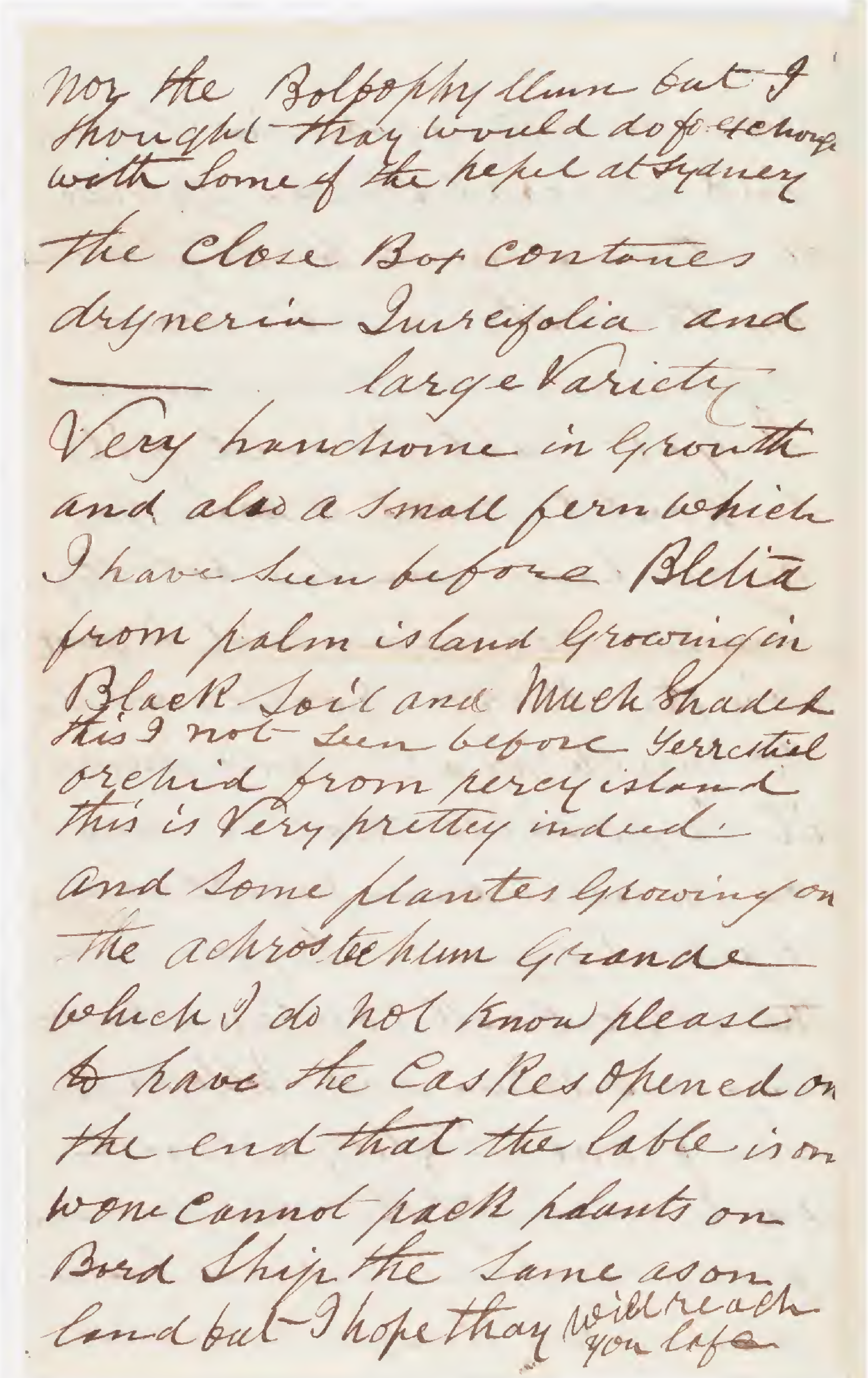
we called at several of the islands as we cam along but did not Go on to the mane land which I am sorry for as I think thare would be some things to be had most of the island are full of Dendrobium undulatum som of the plants from 4 to 6 feet in hight — the Vegetation on thos islands are nearley alike — I Got some few seeds of different things and also some plants for drying



which I find Very defficult to dry at Sea more so when the days are damp I have packed 3 Caskes and [illegible] 1 Close Box with plants which I hope the mail Steamer will take to morrow as we are going to meet it on our way with the Steam lanch I have not labeled the plants but I Keep a memo of them the Small caskes are fild with a Dendrobium from Barrow island this is a lovely orchid. Somthing like Dendrobium monanthum in Colour and size of flower except —



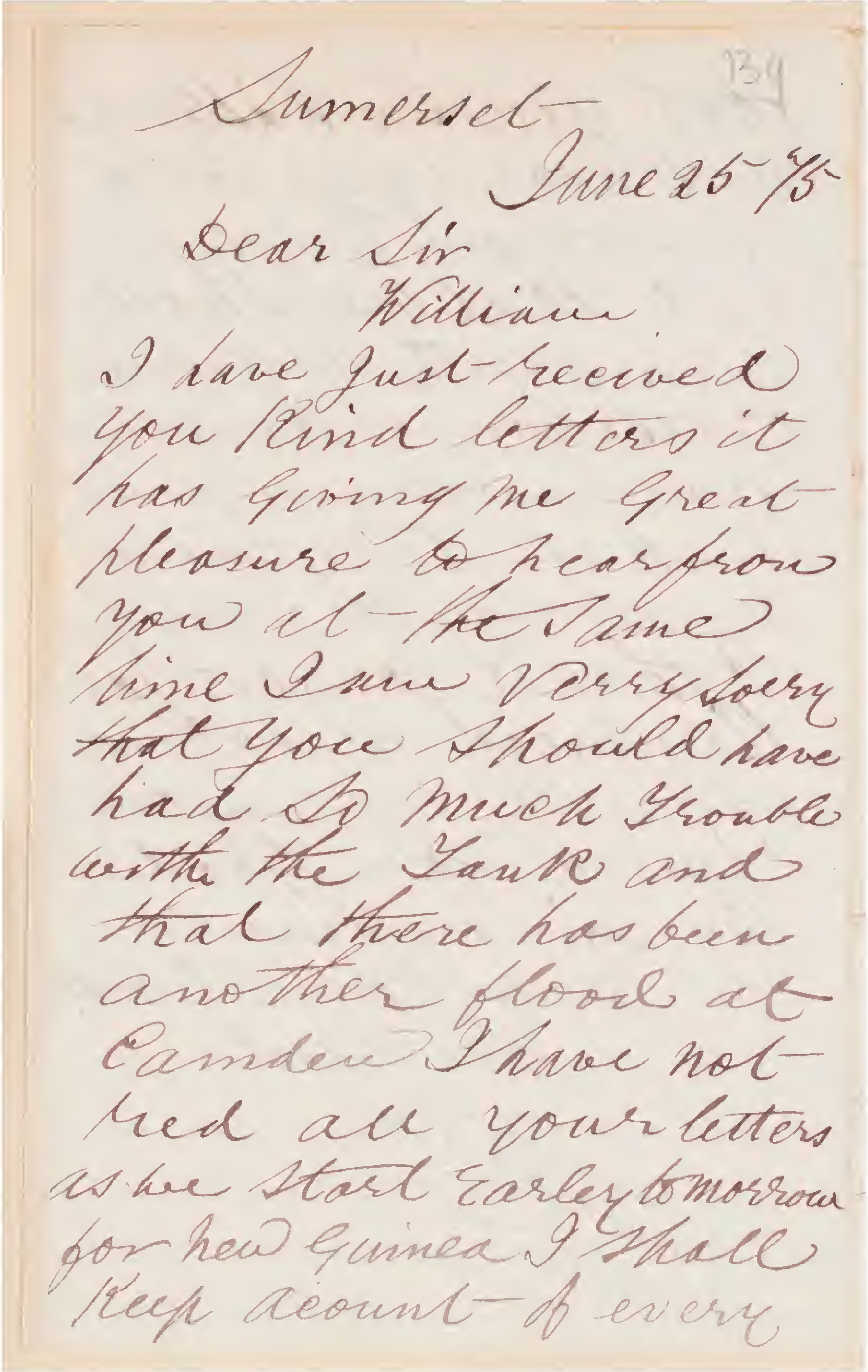
Much Stronger in Growth
and Several flower Spikes
a Stem from 12 to 20 flowers
on the Stem it lookes
Charming in flower —
I Got all I could of it
I should liked to have Got
More but we did not Stay
long at that island it is found
on the Bare rockes exposed
to Much heat — and dryness
it is posable that it may
be dendrosumn bigibbum
but I cannot Say for Sertane
the large Cask contanes dendro
bium undulatum and Bollophyllum
Sps from fitzroy island
and afew of the dendrobium
from Barrow island I darsay
You will not care for d, undulatum



nor the Bolbophyllum but I
thought thay would do fo exchange
with Some of the peple at Sydney

the close Box contanes
drynerria Qurcifolia and
——— large Variety
Very handsome in Growth
and also a small fern which
I have seen before Bletia
from palm island Growing in
Black Soil and Much Shaded
this I not seen before Terrestial
orchid from percy island
this is Very prettey indeed.

and Some plantes Growing on
the achrostechum Grande
which I do not Know please
~~to~~ have the Caskes opened on
the end that the lable is on
wone Cannot pack plants on
Bord Ship the Same as on
land but I hope thay will reach
you safe



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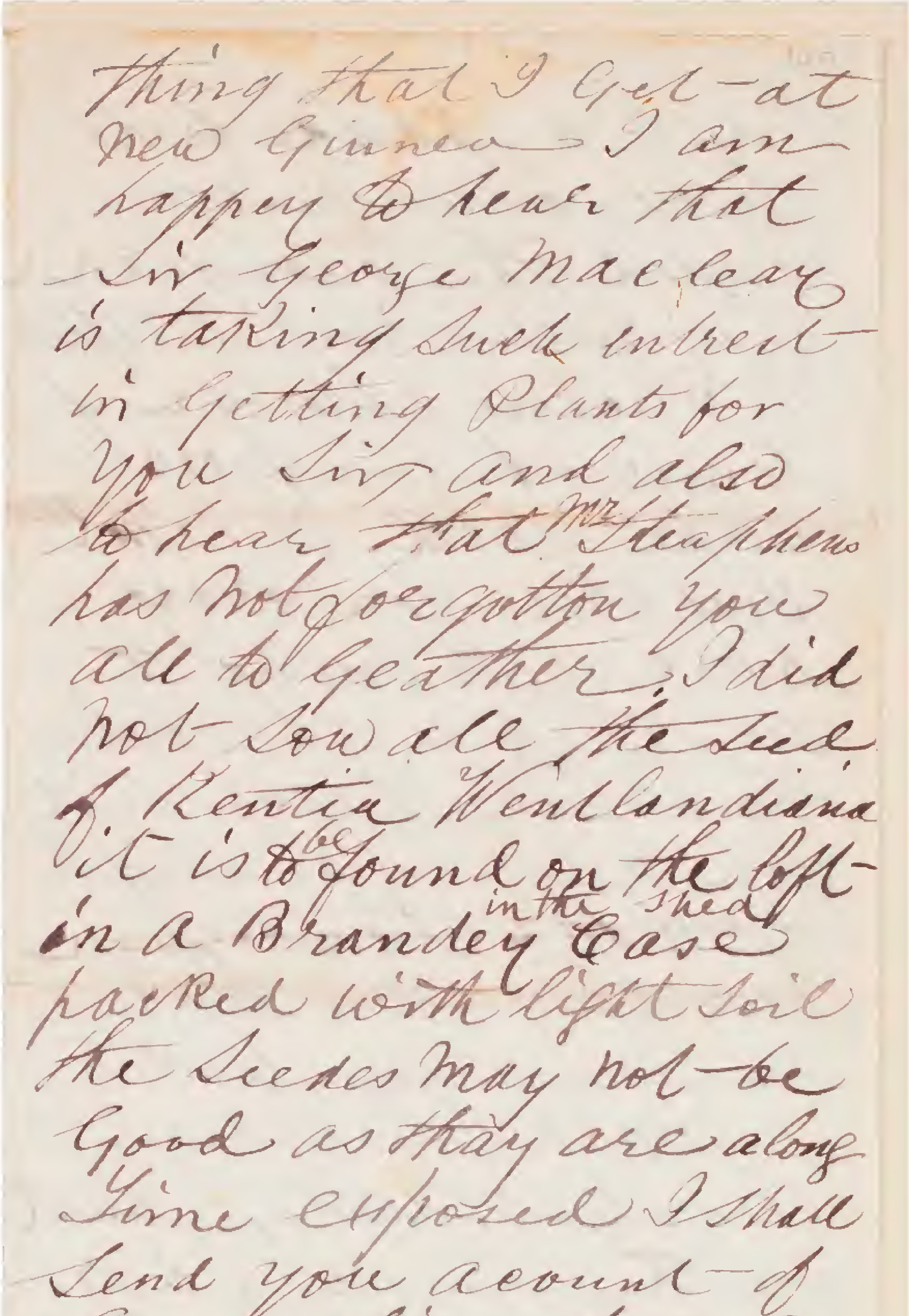
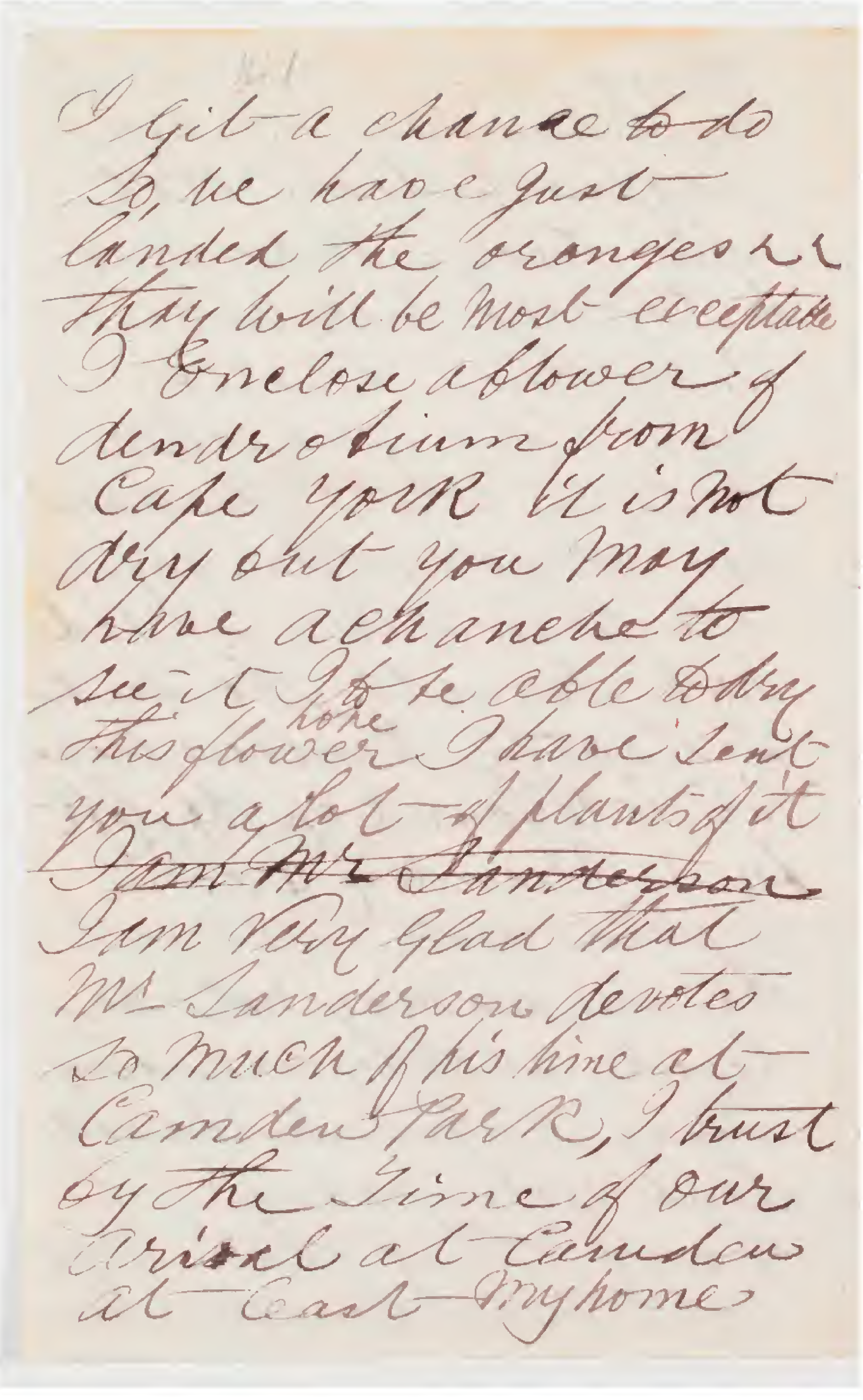
Sumerset
June 25 /75

Dear Sir
William

I have Just Received you Kind letters it has Giving me Great pleasure to hear from you at the Same time I am Verry Sorry that you Should have had So much Trouble with the Tank and that there has been another flood at Camden I have not Red all your letters as we Start Earley tomorrow for New Guinea I Shall Keep acount of every

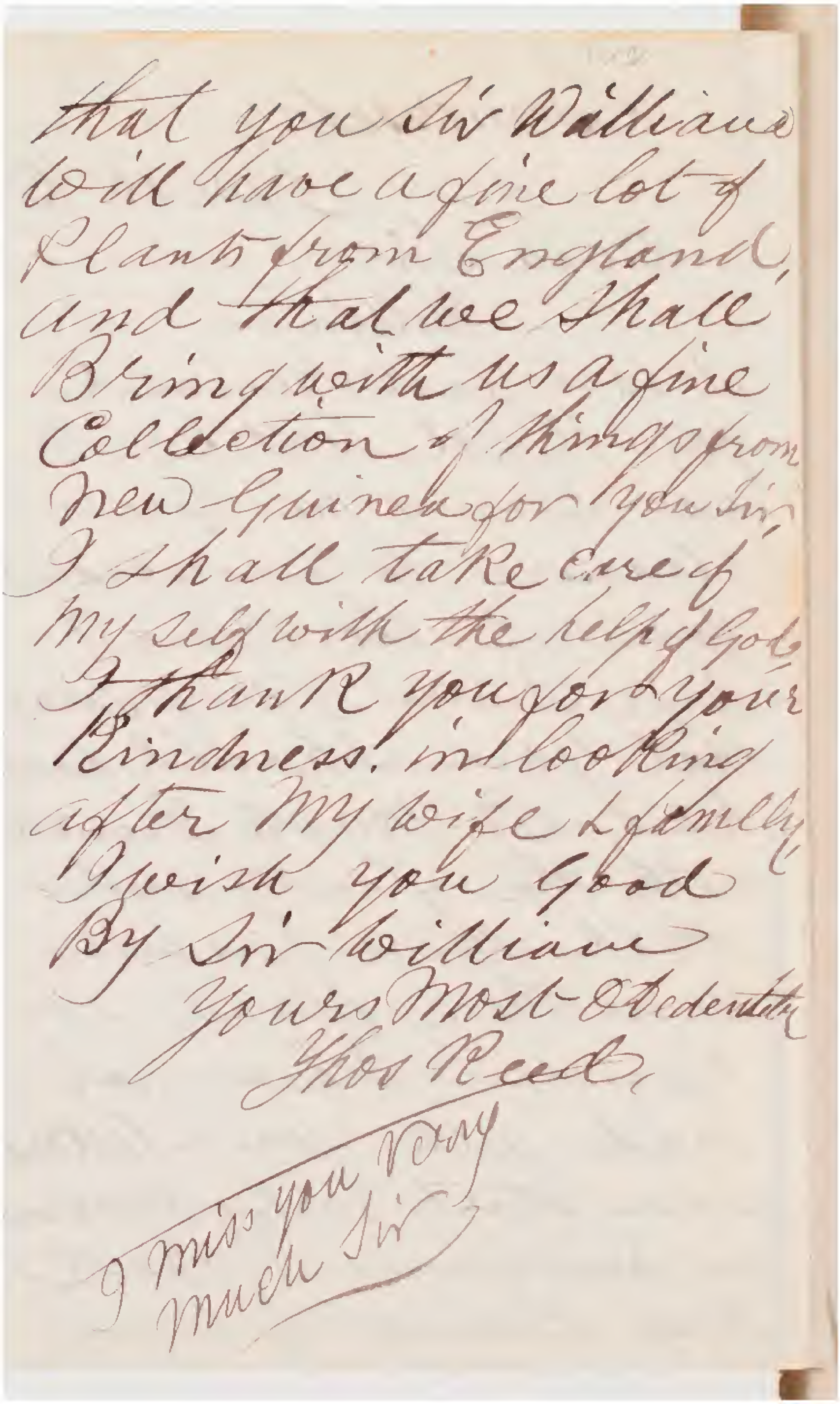


thing that I Get at
new Guinea I am
happy to hear that
Sir George Macleay
is taking such intrest
in Getting Plants for
you Sir and also
to hear ~~that~~ Mr Steaphens
has not forgotton you
all to Geather, I did
not sow all the seed
of Kentia Wendlandiana
it is to be found on the loft
in a Brandey Case in the shed
packed with light soil
the seedes may not be
Good as thay are along
time exposed I shall
send you acount of
Every thing that I Get
at new Guinea should



No 4

I Git a chance to do
So, we have just
landed the oranges & I
thay will be most eceptable
I Enclose a flower of
dendrobium from
Cape york it is not
dry out you may
have a chanche to
see it I hope to be able to dry
this flower I have sent
you a lot of plants of it
~~I am Mr Sanderson~~
I am Very Glad that
Mr Sanderson devotes
so much of his time at
Camden Park, I trust
by the Time of our
Arrival at Camden
at Least my home



that you Sir William
will have a fine lot of
Plants from England,
and that we Shall
Bring with us a fine
Collection of things from
New Guinea for you Sir,
I Shall take care of
My self with the help of God,
I thank you for your
Kindness, in looking
after My wife & family
I wish you Good
By Sir William
Yours Most Obedently
Thos Reed,

I miss you very
much Sir

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Additions and amendments to the rare or threatened vascular plants of Wollemi National Park, central eastern New South Wales

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Abstract: A review and update to the list of significant vascular plant taxa has been made for the c. 500 000 ha Wollemi National Park, approximately 100 km north-west of Sydney, New South Wales. A previous assessment in 2008 revealed the presence of 94 significant taxa, including 15 listed as Endangered and 22 listed as Vulnerable in NSW Threatened Species legislation. New field surveys, coupled with analysis of observation (NSW OEH Bionet Atlas) and specimen collection (Australasian Virtual Herbarium) databases, has added a further 16 significant taxa to the reserve total, elevating it to 110. A revised assessment of the total threatened flora, as listed on the NSW *Biodiversity Conservation Act 2016*, shows there to be 1 Critically Endangered, 19 Endangered, 26 Vulnerable taxa and 2 Endangered Populations. For Commonwealth listed taxa under the *Environment Protection and Biodiversity Conservation Act 1999*, there are 1 Critically Endangered, 9 Endangered and 23 Vulnerable taxa. Sixty-one taxa are currently unrepresented within either legislation and may be considered rare, 8 taxa remain scientifically undescribed (one addition in this revision, *Pultenaea 'monticola'* Mt Irvine), while updated names are provided for two taxa now formally described (*Eucalyptus expressa* and *Prostanthera stenophylla*).

Following assessment of all newly added taxa against IUCN criteria, one currently unlisted species (*Hibbertia coloensis*) qualifies as Critically Endangered, while a second (*Bertya linearifolia*) qualifies as Endangered. Discussion is also provided on six taxa where database records show them to be present within Wollemi, but are here excluded following closer examination.

Keywords: Significant, threatened, rare, Wollemi National Park, IUCN

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Introduction

Wollemi National Park (c. 32° 20' – 33° 30'S, 150° – 151°E) lies approximately 100 km north-west of Sydney, and conserves large areas of dissected sandstone country extending north from the adjoining Blue Mountains National Park to Goulburn River National Park in the Hunter Valley, east to Yengo National Park and Parr State Conservation Area, and west to the settlements of Bylong, Rylstone and Lithgow (Fig. 1). It forms a significant component (49%) of the Greater Blue Mountains World Heritage Area, inscribed in the year 2000 and encompassing seven other adjoining conservation reserves (Blue Mountains, Gardens of Stone, Kanangra-Boyd, Nattai, Thirlmere Lakes and Yengo National Parks, and Jenolan Karst Conservation Reserve).

A previous paper (Bell 2008) outlined 94 significant plant taxa known from the 501 900 ha Wollemi National Park (‘Wollemi’), and over the intervening ten years additional survey and database reviews have uncovered new populations of important species. It is now timely to update the list and conservation status of significant plant species present within the reserve. In 2008, 15 of the 94 significant taxa were listed as Endangered, while 22 were Vulnerable. With this revision, a further 16 taxa have been added to the list of significant species, raising the total to 110. Brief outlines for each of these follows. Readers are referred to Bell (2008) for information on climate, geology and soils present within Wollemi.

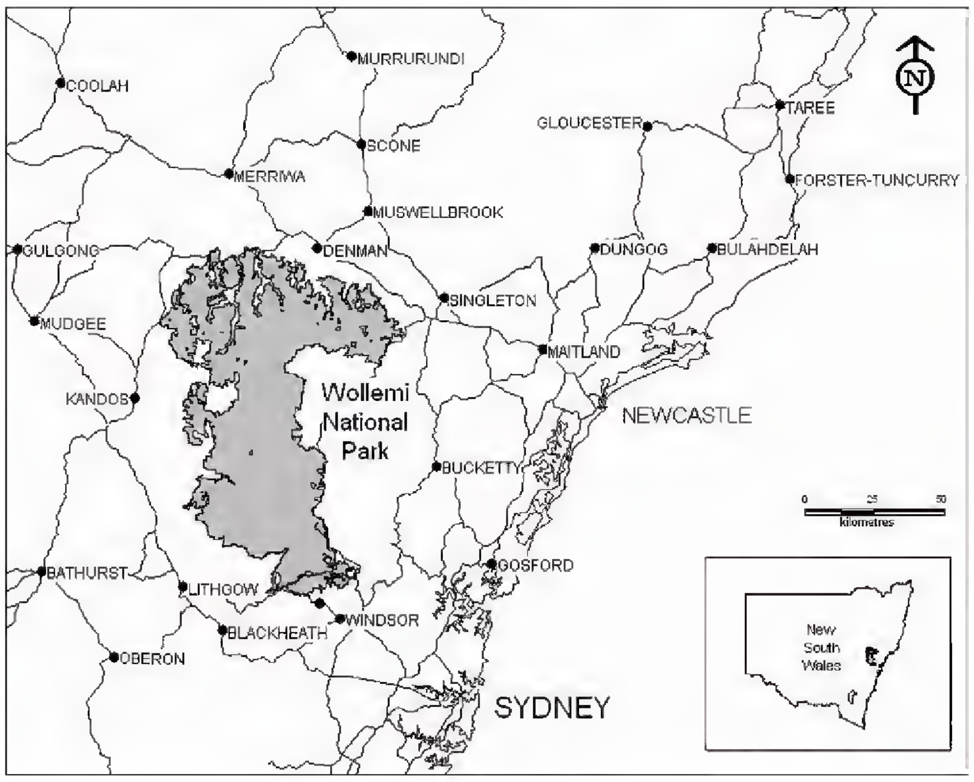

Fig 1. Location of Wollemi National Park, central eastern New South Wales.

Methods

Data obtained through various general and targeted field surveys form the basis of the updated information presented in this paper, undertaken between the years 2008 and 2017. These new surveys were not always designed to specifically uncover significant plant species but aimed to sample all taxa within the different habitats and vegetation communities present. Voucher specimens for all new populations of significant species have been lodged at the National Herbarium of New South Wales (NSW). In addition, a review of the Bionet Atlas database (NSW Office of Environment and Heritage, accessed December 2018 to January 2019) and the Australasian Virtual Herbarium (Council of Heads of Australasian Herbaria, accessed December 2018 to January 2019) was made to collate new collections and observations lodged since 2008. The list of other significant species known from areas adjacent to Wollemi shown in Bell (2008) were a particular focus, but otherwise all significant taxa with records falling within Wollemi were assessed for positional accuracy and independent corroboration prior to acceptance. In some cases, information held in published or unpublished papers, databases or reports was sought to validate additional taxa.

Earlier documentation of significant Wollemi species applied International Union for the Conservation of Nature (IUCN) conservation risk codes to all 94 taxa based on IUCN (2001). New Wollemi taxa have been similarly assessed but using the more recent IUCN (2017) guidelines. To facilitate this, a cleaned dataset (duplicates removed, outliers scrutinized) of all AVH and Bionet Atlas records were combined with personal undatabased observations to allow assessment of Extent of Occurrence (EOO) and Area of Occupation (AOO) for each taxon. The Geospatial Conservation Assessment Tool (GeoCAT: http://geocat.kew.org) was used to calculate EOO and AOO, and allocation was made to the relevant threat category using these figures in concert with IUCN guidelines. The recommended cell width of 2 km was adopted for AOO in all cases, and all available records (NSW and beyond) were utilised. The total number of records included for each assessment of geographical range are indicated in the *n* value cited with resultant EOO and AOO figures.

Throughout this paper, reference to observations included in the NSW OEH Bionet Atlas database use the term ‘Bionet Atlas’, while collections from the Australasian Virtual Herbarium use the acronym ‘AVH’. In general, specimen collections take precedence over observational records given the existence of voucher material that may be reviewed. Specimen collections discussed are identified by their herbarium catalogue number, name of the collector and date of collection, while observation records from the Bionet Atlas include sighting identifier codes. Listing within State or Commonwealth legislation is shown as the *BC Act 2016* (NSW *Biodiversity Conservation Act 2016*) and the *EPBC Act 1999* (Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*).

New additions

1. Bertya linearifolia *Halford & R.J.F.Hend. (Euphorbiaceae)*

Note was made in Bell (2008) of the collection of Type material for *Bertya linearifolia* from northern Wollemi, yet an assessment of its conservation significance was not made. This species remains unlisted on NSW and Commonwealth legislation, but remains a poorly collected entity which is evidently very rare. When describing the taxon, Halford and Henderson (2002a) cite only the Type (NSW 216894, C. Gibson & R. Miller, July 1988) and one other specimen (NSW 194999, C.F. Laseron, July 1924). Since 1988 only a further three specimens have been lodged at herbaria, with one additional observation record (SPJGI3995795) also present in the Bionet Atlas. The last of these falls within Wollemi in the Widden Valley, and was made in open forest of *Eucalyptus fibrosa* and *Callitris gracilis* subsp. *gracilis*, with *Phebalium squamulosum* var. *gracile*, *Leucopogon muticus* and *Lepidosperma laterale*. An additional collection has also been made adjacent to the reserve near Bylong (NSW 892903, S.A.J. Bell, July 2013), suggesting that other plants may be present within much of northern Wollemi however none have surfaced during two decades of survey there. *Bertya linearifolia* consequently remains a very rare and very poorly collected taxon. An EOO of 616 km^2 and an AOO of 24 km^2 ($n = 6$) have been calculated for this taxon.

2. Commersonia rosea *S.A.J.Bell & L.M.Copel. (Malvaceae)*

A wildfire event in northern Wollemi during mid-October 2013 stimulated the germination and growth of *Commersonia rosea* (Fig. 2) across many tens of hectares, comprising tens of thousands of plants (Bell & Holzinger 2015). This species was previously confined to a small number of locations within and adjacent to Goulburn River National Park, and the new Wollemi population represents the largest yet known. At this new location, occupied habitat was predominantly level or near level sandstone rock platforms and ridgelines, often with stunted mallee-like trees of *Eucalyptus dealbata*, and in several places co-occurred with the endangered *Monotaxis macrophylla*. *Commersonia rosea* is currently listed on both the *BC Act 2016* and *EPBC Act 1999* as Endangered. An EOO of 883 km^2 and an AOO of 44 km^2 ($n = 25$) have been calculated for this taxon.

3. Cymbidium canaliculatum *R.Br. (Orchidaceae)*

The Hunter catchment population of the epiphytic orchid *Cymbidium canaliculatum* (Fig. 3) is listed as an Endangered Population under the *BC Act 2016*. While this species can be locally common in grassy forests and woodlands of the Hunter Valley floor and foot slopes, it is rare in the elevated landscapes that comprise Wollemi National Park. Three recent records, however, made within the last decade indicate that the species does occur here. A Bionet Atlas observation (SPJGI4517263) made in February 2011 shows *Cymbidium canaliculatum* to be present within Wollemi in the Doyles Creek valley c. 10 km south-west of Jerrys Plains, although there are no notes on host or associated species. Two observations were later made by the author in a broad valley in the Glen Gallic area of the reserve in November 2014, c. 13 km south of Martindale, each of a single individual in a fork of a mature *Eucalyptus moluccana*. Based on this, and observations made in the Bylong Valley adjacent to the north-western corner of Wollemi (Bell & Driscoll 2014), there are likely to be further individuals of *Cymbidium canaliculatum* across the northern footslopes of the reserve. An EOO of 12,486 km^2 and an AOO of 400 km^2 ($n = 224$) have been calculated for this taxon within the Hunter catchment, although this species also occurs extensively elsewhere in New South Wales, Queensland, the Northern Territory and Western Australia.

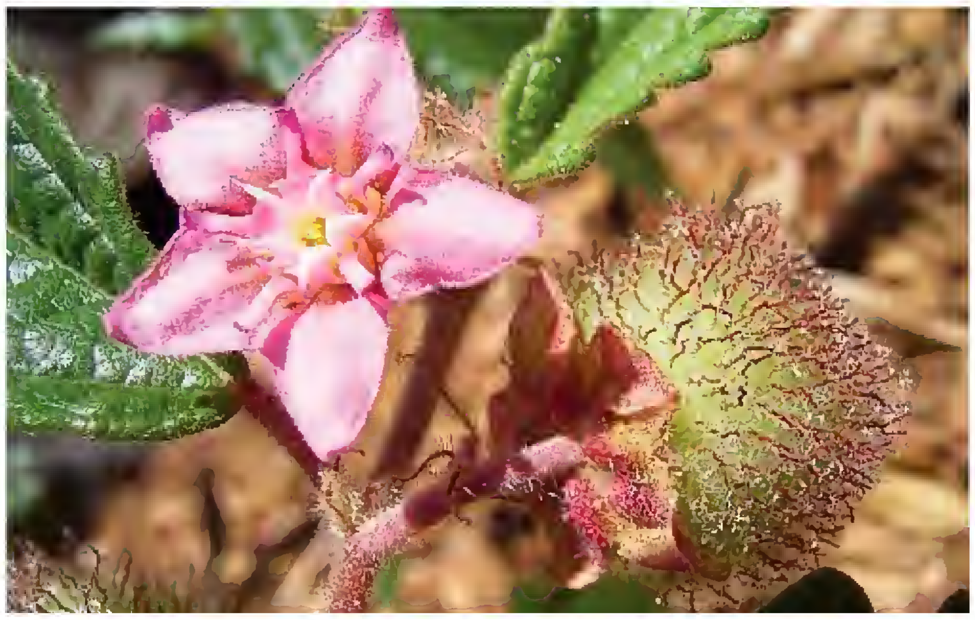

Fig 2. *Commersonia rosea* flowering and fruiting in northern Wollemi, October 2014.

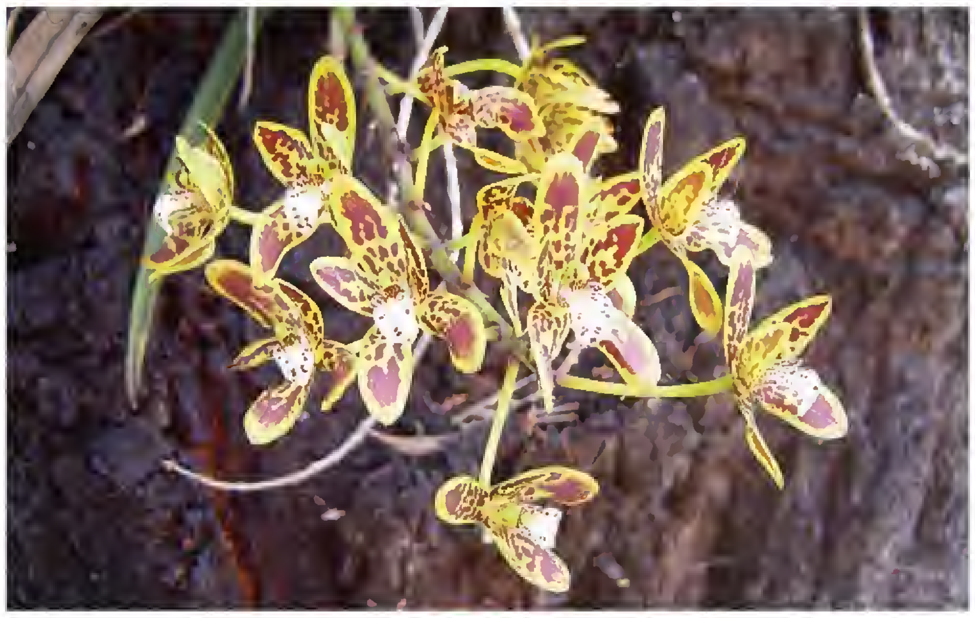

Fig 3. *Cymbidium canaliculatum* flowering near northern Wollemi, November 2008.

4. Dillwynia tenuifolia *DC. (Fabaceae, Faboideae)*

Dillwynia tenuifolia (Fig. 4), listed as Vulnerable on the *BC Act 2016*, is historically recognised as a species of the Cumberland Plain and associated shale ridges occurring at low elevation in that vicinity (James et al 1999; Rymer et al 2002; Fairley 2004). Ongoing survey in southern Wollemi has uncovered several populations of this species which have extended the known range into the Wollemi Creek and Putty districts, both within Wollemi and on adjacent private lands. The long-standing disjunct records of this species at Darkey Creek (NSW 393370, C.E.B.H. Burgess, January 1962) and at Milbrodale (Maryott-Brown & Wilks 1993) are now not so remote from proximate populations. Collections near Wollemi Creek (NSW 897213, S.A.J. Bell, June 2008; NSW 973926, S.A.J. Bell, September 2008) describe habitat as open forest of *Eucalyptus fibrosa* on gravelly soils (where it was abundant), and in some cases on rocky sandstone ridgelines (considerably less abundant). Further north near Putty, *Dillwynia tenuifolia* occurs in open forest of

Eucalyptus prominula, Angophora costata and *Eucalyptus punctata* (NSW 975443, S.A.J. Bell, May 2012) and open forest of *Eucalyptus crebra* and *Eucalyptus sparsifolia* (NSW 975440, S.A.J. Bell, May 2011). Other collections shown in AVH have been incorrectly positioned, with some (such as NE 45333, J.B. Williams, November 1974) from the Mellong area of Wollemi inconsistent with the written description ("*c. 15 km SSW of Windsor, near Castlereagh*"). An EOO of 10,713 km^2 and an AOO of 560 km^2 (n = 1,924) have been calculated for this taxon. Significant outliers in the Kanangra-Boyd (NSW 465622, I. Crawford, June 1998), Belanglo (CANB 321056.1, P. Snowdon, 1964) and Murrumbidgee River (NSW 458292, I. Crawford, September 1995) areas have been omitted from this assessment pending confirmation.

5. Eucalyptus fracta *K.D.Hill (Myrtaceae)*

Collections of a small ironbark made along the Glen Gallic Trail of northern Wollemi in 2012 were determined initially as *Eucalyptus fracta* (Fig. 5), although there remains some uncertainty with this identification. *Eucalyptus fracta* principally occurs at the eastern end of the Broken Back Range near Pokolbin (Hill 1997; Copeland & Hunter 2005), some 65 km to the south-east of Glen Gallic. In the field the small stature, bare upper branches and fruit morphology were sufficiently consistent with known populations of *Eucalyptus fracta* along the Broken Back Range to support the initial diagnosis, but since that time there has been no advancement in identity. This collection (NSW 984037, S.A.J. Bell, June 2012) is currently housed in AVH as an indeterminate *Eucalyptus* taxon, and re-inspection of this population is warranted. The nearest confirmed collection of *Eucalyptus fracta* lies c. 40 km to the south-east of Glen Gallic (and approximately mid-way to the Broken Back Range population), along the northern escarpment of Yengo National Park near Milbrodale (NSW 862264, S.A.J. Bell, June 2006), suggesting that outliers such as at Glen Gallic are not unusual. Until such time that the Glen Gallic population can be re-assessed, *Eucalyptus fracta* (listed as Vulnerable on the *BC Act 2016*) is here considered a tentative addition to the Wollemi flora. An EOO of 176 km^2 and an AOO of 44 km^2 (n = 35) have been calculated for this taxon.

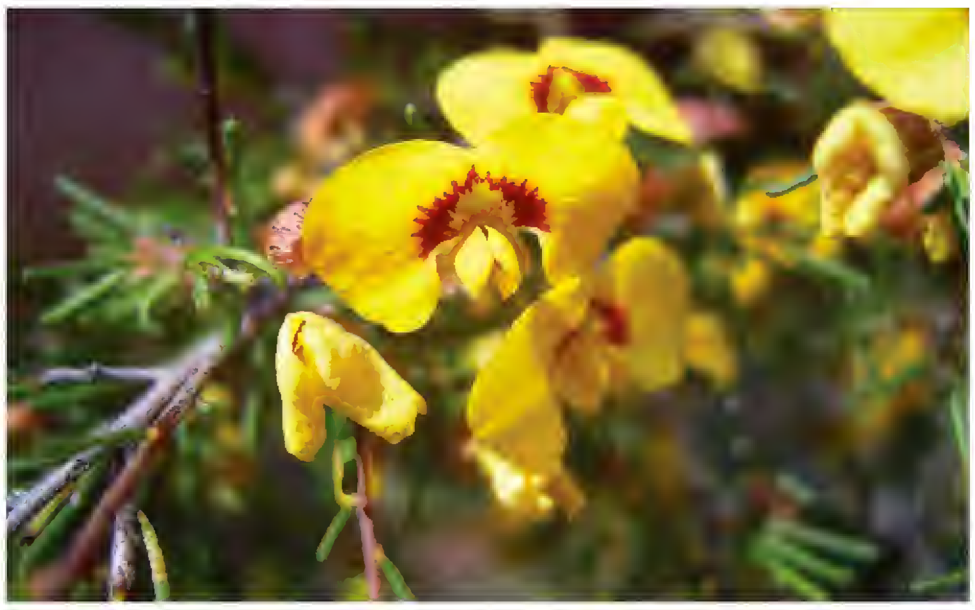

Fig 4. *Dillwynia tenuifolia* flowering in western Sydney, November 2004.

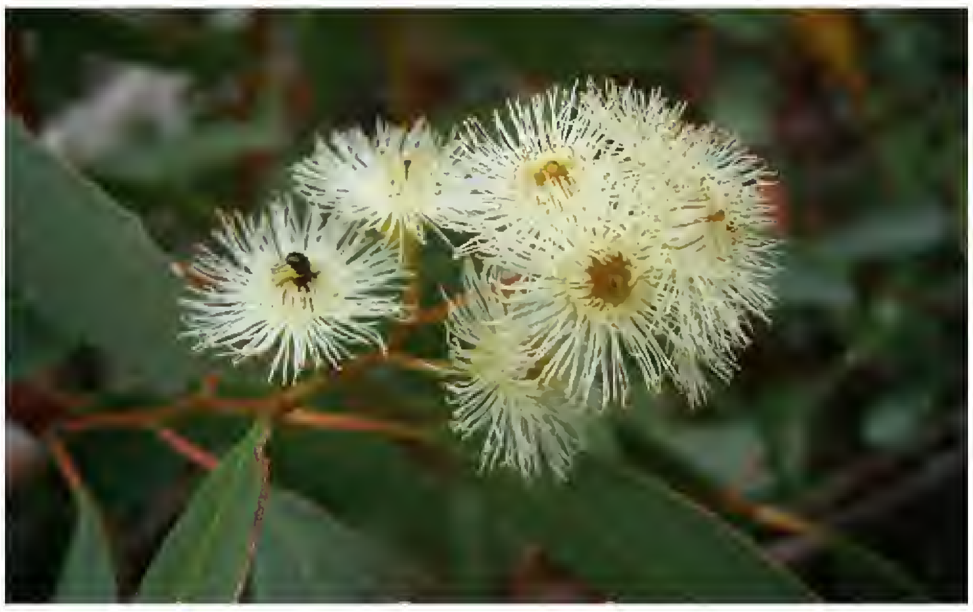

Fig 5. *Eucalyptus fracta* flowering on the Broken Back Range, December 2004.

6. Eucalyptus michaeliana *Blakely (Myrtaceae)*

Eucalyptus michaeliana is known from Yengo National Park and nearby areas, within the Wollombi Brook and the upper MacDonald River catchments. Indeed, NSWDECC (2008) reported that many of the sheltered drainage lines within central Yengo are dominated by this species. It is not surprising, therefore, that surveys within Wollemi would also uncover previously unknown populations of this taxon. Similar to the central Yengo habitat, within Wollemi *Eucalyptus michaeliana* was found to dominate sheltered habitats in tributaries of Wollemi Creek to the north-west of Mellong, although at this stage it is unknown how extensive these populations are. *Eucalyptus michaeliana* is a rare species spread across three meta-populations (Yengo-Wollemi, Oxley Wild Rivers-Guy Fawkes, Mt Barney in Queensland) and is not listed in threatened species legislation. An EOO of 28,697 km^2 and an AOO of 560 km^2 (n = 195) have been calculated for this taxon.

7. Grammitis stenophylla *Parris (Polypodiaceae)*

Two records in the Bionet Atlas show this small epiphytic fern for sites in the far south of Wollemi. One of these (SPJGI4614837) is an observation record made during remote helicopter survey of the Wollangambe River catchment in 2012. There appear to be no collections associated with this record, but habitat and landscape position are suitable. The second record refers to a specimen collection made from Gospers Creek on damp sandstone rocks (NSW 393914, R.G. Coveny, May 1976), and was confirmed by the species authority (B.S. Parris) in 1994. Given the superficial similarities of this species to other NSW *Grammitis* taxa (of which there are only two), it is likely that this taxon has been misidentified in the past and is present in many of the sheltered gullies in the southern Wollemi area. *Grammitis stenophylla* is listed as Endangered on the *BC Act 2016* however AVH records show it is distributed along the majority of the Australian coastal hinterland. An EOO of 820,124 km^2 and an AOO of 568 km^2 (n = 194) have been calculated for this taxon.

8. Grevillea parviflora *R.Br. subsp.* parviflora *(Proteaceae)*

Grevillea parviflora subsp. *parviflora* (Fig. 6) principally occurs in two main meta-populations within the Sydney Basin, one in south-western Sydney and the other between Wyong and Karuah. Additional to these, however, is a new smaller meta-population in the Mellong area of Wollemi and the adjacent Yengo National Park. During surveys in Wollemi in 2008, flowering and apparently clonal stands of this taxon were located in the Culoul Creek area just south of Mellong (NSW 975735, S.A.J. Bell, September 2008), and also in tributaries of Wollemi Creek to the north-west of Mellong (NSW 897212, S.A.J. Bell, June 2008; NSW 975732, S.A.J. Bell, September 2008). Habitat at these locations included open forest of *Eucalyptus fibrosa, Acacia undulifolia, Daviesia squarrosa, Macrozamia reducta, Lomandra glauca* and *Dianella revoluta* on lower slopes and flat ridges, with the threatened *Dillwynia tenuifolia* also present in the area. Further support for this new meta-population in the Mellong-Putty locality is provided by the several hundred records of this taxon shown in the Bionet Atlas for a private property immediately east of the Putty Road at Tinda Creek (e.g. SIXRI0988130, SIXRI0988252, SIXRI0988607). *Grevillea parviflora* subsp. *parviflora* is listed as Vulnerable on both the *BC Act 2016* and *EPBC Act 1999*. An EOO of 20,049 km^2 and an AOO of 912 km^2 ($n = 4{,}533$) have been calculated for this taxon, with significant outliers near Temora (CANB 779964.1, J. Johnston, September 1979) and Numeralla (CBG 9506469.1, M. Parris, October 1971) omitted.

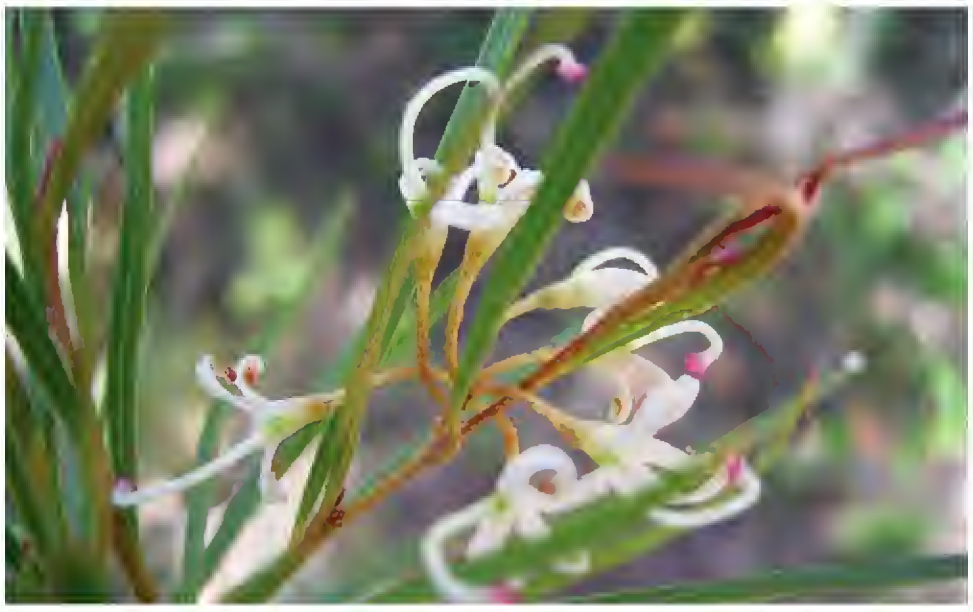

Fig 6. *Grevillea parviflora* subsp. *parviflora* flowering on the Central Coast, December 2003.

9. Hibbertia coloensis *Toelken (Dilleniaceae)*

The showy shrub *Hibbertia coloensis* is known from only five AVH collections made between 2000 and 2008 along the Colo River in south-eastern Wollemi, where it grows in alluvial sand with *Tristaniopsis laurina* amongst sandstone boulders (Toelken 2013). Although a number of botanists have explored the south-eastern parts of Wollemi over many years, and apparently suitable habitat is more widespread, specimens of *Hibbertia coloensis* are only known from a short stretch (c. 1.2 km) of the Colo River. Notes associated with the Type specimen (NSW 721048, A.N. Rodd, October 2004) describe abundance as 'locally frequent' (Toelken 2013), however it is unknown if this comment applies only to the collection point or over a larger stretch of habitat. On current data, this species is therefore highly restricted and further targeted searches elsewhere along the Colo River and nearby larger creek systems such as Wollemi Creek are recommended. *Hibbertia coloensis* is a poorly collected and highly restricted rare taxon, but is currently unlisted on threatened species legislation. Although not documented, the susceptibility of this taxon to flood events may pose a particular threat, given its known habitat is unconsolidated alluvium of the larger creeks. An EOO of 4 km^2 and an AOO of 4 km^2 ($n = 5$) have been calculated for this taxon.

10. Homoranthus darwinioides *(Maiden & Betche) Cheel (Myrtaceae)*

There is a single collection of *Homoranthus darwinioides* shown in AVH for a site near Baerami on the northern edge of Wollemi (NSW 204051, B.G. Briggs, April 1987), but this locality is in error as the collection notes clearly state "*Cox's Gap, c.28 km west-southwest of Sandy Hollow*". Cox's Gap comprises a section of the Bylong Valley Way that is completely encompassed by Wollemi NP at this location, and the occurrence of *Homoranthus darwinioides* there appears valid. However, there have been no collections made from that site since 1987 (>30 years), and it is unknown if the species remains there. A second record from the Oz Mountain district on the western edge of Wollemi (CANB 682785.1, L.M. Copeland & T. Daniels, September 2000) is also questionable, given that site is known for the related *Homoranthus cernuus*: Copeland et al (2011) cite a specimen from this same area lodged by the same collectors on the same date as representative of *Homoranthus cernuus*. As a consequence, *Homoranthus darwinioides* remains known from Wollemi only through the 1987 collection at Cox's Gap, where at that time it was considered "*locally frequent*". Targeted searches and new collections from this locality would be desirable. *Homoranthus darwinioides* is listed as Vulnerable on both the *BC Act 2016* and the *EPBC Act 1999*. An EOO of 4,639 km^2 and an AOO of 108 km^2 ($n = 68$) have been calculated for this taxon, omitting the dubious record from Oz Mountain and re-projecting the Briggs record to the correct locality of Cox's Gap.

11. Monotaxis macrophylla *Benth. (Euphorbiaceae)*

Wildfire east of the Glen Gallic Trail near Martindale in mid-October 2013 stimulated mass germination of *Monotaxis macrophylla* (Fig. 7), a species largely unknown from the reserve prior to this event (Bell & Holzinger 2015). At this locality *Monotaxis* occurred predominantly on level or near level sandstone rock platforms and ridgelines, often co-occurring with the endangered *Commersonia rosea*. The first record of *Monotaxis* for Wollemi appears to be that made by Colin Gibson and Rob Miller in 1999, at Crypt Hill within Baerami Creek catchment, also "*scorched about a year or so*" previously (Gibson 2002). Crypt Hill lies c. 16 km to the west of the Glen Gallic population, and according to observation notes that population also occurred on sandstone rock platforms on ridgelines. Elsewhere in NSW, *Monotaxis macrophylla* is widely scattered in locations such as Cobar, Howell, Glen Innes, Torrington, Bega and Moruya (Halford & Henderson 2002b; AVH records). Mass germination after fire has been reported for this species in many other locations, such as in South East Forests National Park near Bega (NSW 989541, J. Miles, December 2014) and on the Northern Tablelands (NE 68038, J.B. Williams, November 1998). *Monotaxis macrophylla* is listed as Endangered on the *BC Act 2016*. An EOO of 910,682 km^2 and an AOO of 396 km^2 (n = 149) have been calculated for this taxon.

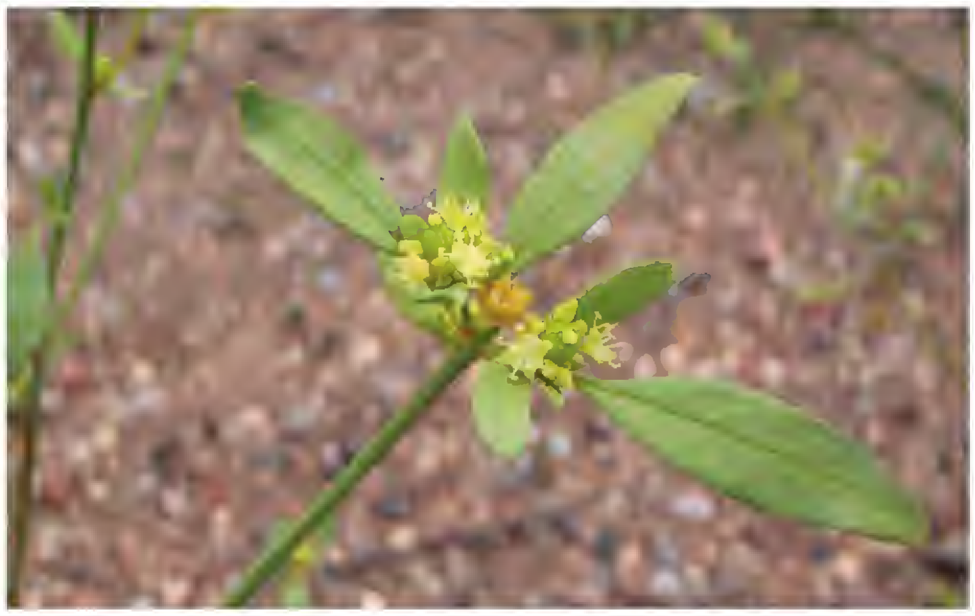

Fig 7. *Monotaxis macrophylla* flowering and fruiting in northern Wollemi, October 2014.

12. Philotheca ericifolia *(A.Cunn. ex Benth.) Paul G.Wilson (Rutaceae)*

Philotheca ericifolia was removed from the (then) NSW *Threatened Species Conservation Act 1995* in late 2009. Prior to this it was listed as a Vulnerable species, but the extent of new records and size of populations uncovered at that time implied that it was a species no longer under great threat. Despite this, the species remains listed as Vulnerable under Commonwealth legislation. Several AVH collections have been made in the Dunns Swamp area of western Wollemi, near Olinda, from as early as 1969. This area has had a long history of plant survey by professional and amateur botanists due to the proximity of camping grounds near to the swamp, and as a consequence collections of many significant species have been made there. The most recent collection of *Philotheca ericifolia* (NSW 493735, R.L. Johnstone, December 2005) found it to be plentiful in habitat described as "*Pagoda outcrops on rocky ridge. Heathland in pockets, with* Leptospermum parvifolium, L. arachnoides, Calytrix tetragona, Ochrosperma oligomerum, Leionema lamprophyllum, Grevillea evansiana, Dillwynia rudis, Pultenaea *sp.* Olinda, Patersonia *sp. Skeletal sandy soil on sandstone*". Some other records for this species are unsubstantiated or unvouchered. An observation record contained in the Bionet Atlas (SPJGI3207733) shows this species for a location near Oz Mountain on the western fringe of Wollemi, made in July 1997. Examination of the original notes and collection associated with this record reveal that confirmation could not be achieved in 1997 due to an absence of fertile material, and this record should now be considered unconfirmed. A more recent Bionet Atlas observation (SJJSI0663883) from May 2017 occurs just within northern Wollemi at Baerami, and despite an absence of voucher specimen is assumed valid. No notes on population size and habitat are available for this record. *Philotheca ericifolia* is listed as Vulnerable on the *EPBC Act 1999*, but remains unlisted on the *BC Act 2016*. An EOO of 72,022 km^2 and an AOO of 336 km^2 (n = 131) have been calculated for this taxon.

13. Pomaderris queenslandica *C.T.White (Rhamnaceae)*

Pomaderris queenslandica (Fig. 8) occurs in a number of locations in the Goulburn River valley to the immediate north of Wollemi and in the upper Hunter district more generally (Bell 2001), but collections from within Wollemi itself have been few. New populations have been located, however, in the Kerrabee, Glen Gallic, Reedy Creek and Widden areas over the past decade. At Kerrabee, *Pomaderris queenslandica* occurs in a dry creek line with *Eucalyptus punctata, Acacia penninervis* subsp. *penninervis, Bursaria spinosa* and *Dodonaea viscosa* var. *cuneata*, over a ground layer of *Microlaena stipoides* var. *stipoides*, *Digitaria diffusa* and *Dichondra repens*. Further east at Glen Gallic, *Pomaderris queenslandica* was recorded on a ridgeline in open forest of *Eucalyptus fibrosa* sens. lat., with *Leucopogon muticus, Macrozamia reducta, Grevillea montana, Acacia piligera, Rytidosperma pallidum* and *Lomandra confertifolia* subsp. *rubiginosa*. This ridgeline habitat is unusual for the species, and although not searched it is suspected that nearby sheltered slopes and gullies support many more individuals. Similarly, on the escarpment above Reedy Creek scattered plants occur in open forest of *Angophora costata, Eucalyptus sparsifolia* and *Eucalyptus punctata*, with *Acacia penninervis* subsp. *penninervis* and *Daviesia ulicifolia* subsp. *ulicifolia*. Additionally, a Bionet Atlas record (SIXRI0074080), made in October 2009, shows this species for a small tributary within the lower Widden Valley (c. 8km south of its junction with the Goulburn River), but no details are available on habitat there. Other collections have been made in the Bylong Valley, adjacent to Wollemi (Bell & Driscoll 2014), and it is suspected that this species is widespread yet occurs only in small stands. *Pomaderris queenslandica* is listed as Endangered on the *BC Act 2016*. An EOO of 582,441 km^2 and an AOO of 632 km^2 (n = 303) have been calculated for this taxon, which outside of Wollemi extends across much of north-eastern New South Wales and eastern Queensland.

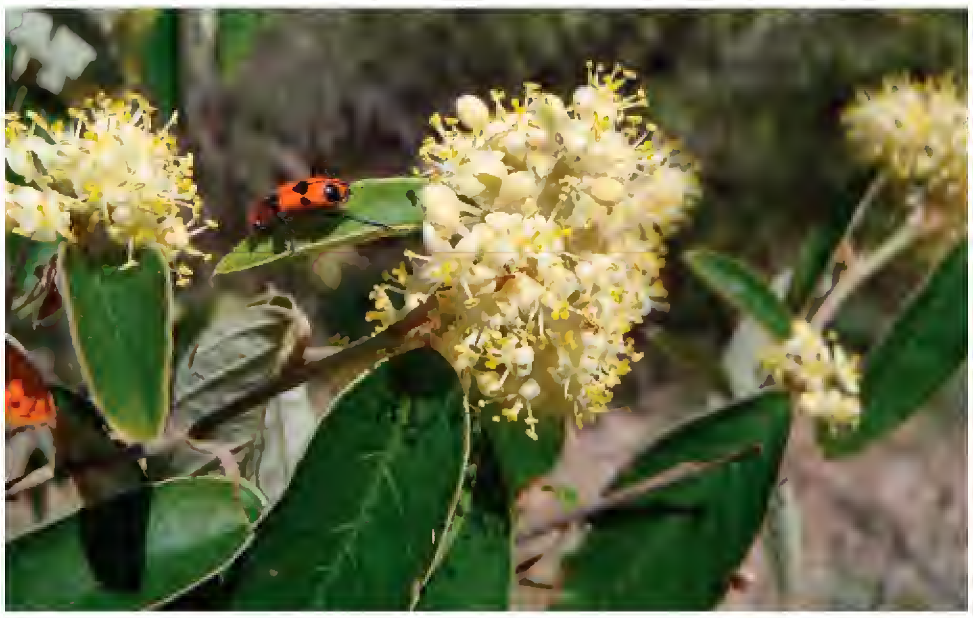

Fig 8. *Pomaderris queenslandica* flowering near north-western Wollemi, September 2015.

14. Prostanthera cineolifera *R.T.Baker & H.G.Sm. (Lamiaceae)*

The taxonomy of *Prostanthera cineolifera* (Fig. 9) has had a complicated history which is only now beginning to become clear. For a long time this taxon was difficult to separate from the closely related *Prostanthera lanceolata* and *Prostanthera ovalifolia*, and as a consequence the distribution of it was uncertain. Current taxonomic research is suggesting that *Prostanthera cineolifera* is more widespread than previously thought, with new collections recently being made from the north-western Wollemi area. Additionally, re-determinations of older collections from Wollemi are showing that they most closely match *Prostanthera cineolifera* (R. Palsson, pers. com.). One collection made in the Bylong Labyrinth section of Wollemi in the late 1990s (NSW 424206, S.A.J. Bell, October 1998) was initially determined as the threatened *Prostanthera discolor*, but is now considered to be the most westerly known population of *Prostanthera cineolifera*. Plants from this population were independently viewed and dismissed as *Prostanthera discolor* as early as 1999 by Gibson (2002), suggesting it instead to be a form of *Prostanthera ovalifolia*. More recently, as part of her revision to this group Ruth Palsson (UNE) inspected this population and attributed plants to *Prostanthera cineolifera*. Likely additional stands of this same taxon have been found in the Bylong State Forest area adjoining Wollemi, where it is plentiful, and specimens from there are currently attributed to *Prostanthera ovalifolia* (Bell & Driscoll 2014). *Prostanthera cineolifera* is listed as Vulnerable on both the *BC Act 2016* and the *EPBC Act 1999*. An EOO of 5,382 km^2 and an AOO of 80 km^2 ($n = 107$) have been calculated for this taxon, with the removal of some outliers: North Coast records of *Prostanthera cineolifera* in the Grafton and Walcha regions (e.g. NSW 973540, A. Carty, October 2014) are thought to represent a different un-named taxon, while specimens databased for the St Albans district (e.g. NSW 976082, K. Thumm, October 2014) represent the entity *Prostanthera* sp. Hawkesbury (B.J.Conn 2591).

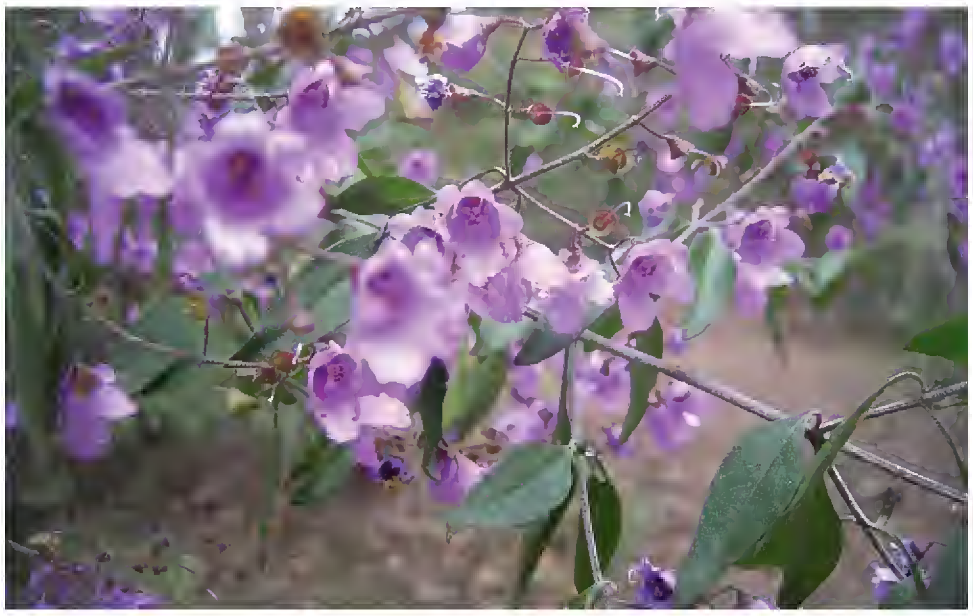

Fig 9. *Prostanthera cineolifera* flowering in Pokolbin State Forest, October 2010.

15. Pultenaea 'monticola' *Mt Irvine (Fabaceae, Faboidea)*

Pultenaea glabra sens. lat. was included in the revision of *Pultenaea* possessing ovaries that were glabrous or supported tufted hairs (de Kok & West 2002). In that revision, *Pultenaea weindorferi* (from Victoria), *Pultenaea* sp. Olinda (Coveny 6616) (= *P*. sp. E) and *Pultenaea villosa* var. *glabrescens* Benth. (both New South Wales), and *Pultenaea setulosa* sensu Batianoff (Queensland) were placed in synonymy with *Pultenaea glabra*. However, as currently accepted in New South Wales *Pultenaea glabra* encompasses these and several other forms and further taxonomic work is a priority. One of these forms, occurring at high elevation in the Blue Mountains-Wollemi region on Wianamatta shale and adjacent areas, is *Pultenaea 'monticola'* Mt Irvine (Douglas & David 2018). This entity reportedly differs from *Pultenaea glabra* sensu str. in the broader and bright green (not glaucous) leaves with a less pungent mucro, axillary rather than terminal inflorescences, and simple rather than furcate branching (Fig. 10). From the related *Pultenaea flexilis* it differs by the involute rather than flat leaves with sub-parallel veins, and the bright green leaf colour. *Pultenaea 'monticola'* has been recorded as the dominant understorey taxon in open forest following fire within southern Wollemi north of Itchenstoke and near Green Scrub. While not currently described nor listed as threatened, this taxon remains of some significance due to uncertainty around its taxonomic position and distribution. EOO and AOO have not been calculated for this entity due to the uncertainty in point record locations and confusion with *Pultenaea glabra* and *Pultenaea flexilis*.

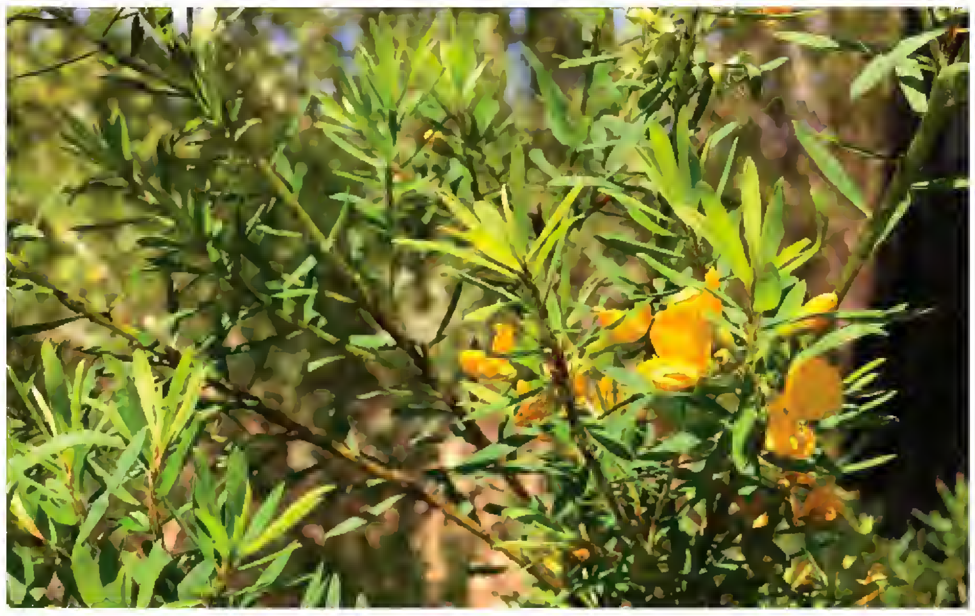

Fig 10. *Pultenaea 'monticola'* Mt Irvine, flowering in Blue Mountains National Park near Mt Irvine December 2018 (Photograph: Steve Douglas).

16. Senecio linearifolius *var.* dangarensis *Belcher ex I.Thomps. (Asteraceae)*

Formerly known only from the type location at Mt Dangar in Goulburn River NP, a new population of *Senecio linearifolius* var. *dangarensis* (Fig. 11) was found recently by local residents Trevor and Andrew Woolley, on the northern edge of Wollemi c. 30 km to the south-east of Mt Dangar. At the time of survey in 2017 this site supported an estimated 14,000 individuals, exceeding that calculated for Mt Dangar (Bell 2017a). Habitat at this site is similar to that at Mt Dangar, both supporting woodland of *Eucalyptus moluccana* and occasionally *Brachychiton populneus*, on basalt soils with a well-developed grass and herb layer. Drought conditions over the last year have reduced the number of viable plants at both the Mt Dangar and Wollemi sites considerably. *Senecio linearifolius* var. *dangarensis* is listed as Endangered on the *BC Act 2016*. An EOO of 21 km^2 and an AOO of 16 km^2 ($n = 75$) have been calculated for this taxon, using a cleaned dataset incorporating AVH, Bionet Atlas and undatabased records collected as part of current research on this species.

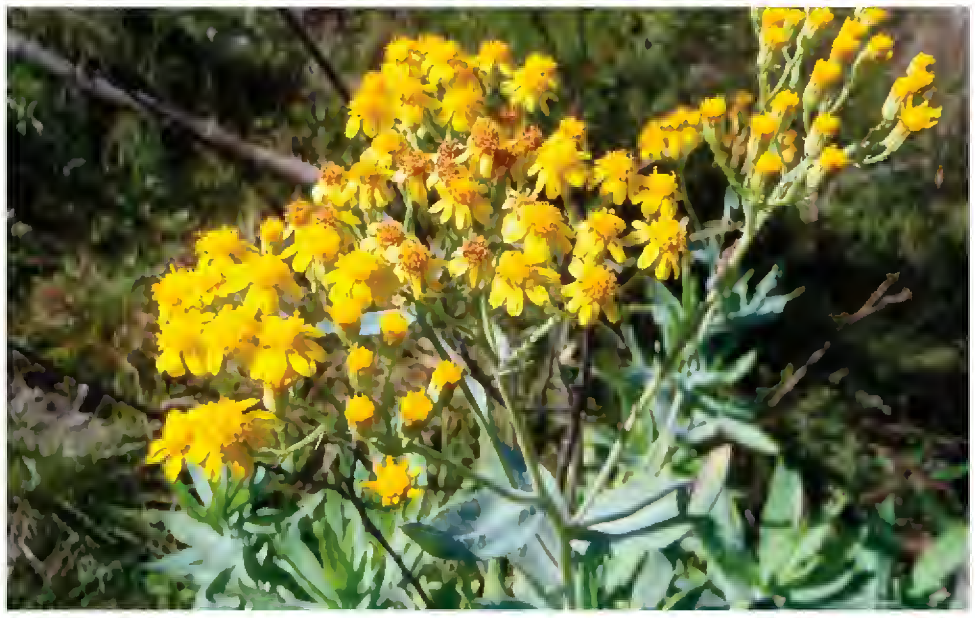

Fig 11. *Senecio linearifolius* var. *dangarensis* flowering in Goulburn River National Park, October 2015.

Updated taxonomy

Two taxa previously discussed in Bell (2008) as significant Wollemi species have now been formerly described (see below). No progress has been made on the taxonomy of other un-named species noted in that paper, including *Diuris* sp. aff. *punctata* (Colo River), *Eucalyptus* sp. 'Howes Swamp Creek' (Doherty 26), *Leionema* sp. 'Colo River' (Weston 2423), *Pomaderris* sp. aff. *nitidula* (Glen Gallic), *Prostanthera* sp. aff. *rotundifolia* (Mt Iris), *Pultenaea* sp. Olinda (Coveny 6616), and *Rulingia* sp. aff. *dasyphylla* (Goulburn River Valley).

Eucalyptus expressa *S.A.J.Bell & D.Nicolle (Myrtaceae)*

The tall stringy bark tree referred to in Bell (2008) as *Eucalyptus* sp. aff. *eugenioides* (Bees Nest Ridge), and recorded in Wollemi along the Hunter Range in the eastern portions of the reserve, has now been named as *Eucalyptus expressa* (Bell & Nicolle 2012). New records for Wollemi have also surfaced over the last decade, shown in the Bionet Atlas for Martindale Creek (SIXRI0605800) and in AVH for the Wolgan River area (NSW 496183, I. Olsen, June 2001; NSW 1001064, G.P. Phillips, September 2017). Material collected by N.C.W. Beadle (also from the Wolgan River) in July 1937 has been recently re-determined as *Eucalyptus expressa*, making this the earliest known collection of this taxon. Bell and Nicolle (2012) suggested a conservation risk code of 2KC, and an IUCN category of Data Deficient for this species.

Prostanthera stenophylla *B.J.Conn (Lamiaceae)*

Prostanthera sp. A (Rylstone), discussed in Bell (2008) for western parts of Wollemi near Dunns Swamp, has now been described as *Prostanthera stenophylla*. Apart from a dubious collection from the Canberra district, *Prostanthera stenophylla* is believed to be endemic to Wollemi where it occurs amongst the sandstone 'pagodas' in dry sclerophyll forest dominated by *Eucalyptus piperita, Eucalyptus rossii* and *Callitris endlicheri* (Conn 2006). This species is currently not listed as threatened, although Conn (2006) suggested that it be considered vulnerable due to its highly restricted distribution.

Excluded records

Six taxa shown in the Bionet Atlas and AVH databases for Wollemi have been dismissed from occurring in the reserve for the reasons discussed below.

Acacia alaticaulis *Kodela & Tindale (Fabaceae, Mimosoideae)*

Acacia alaticaulis was recorded along the Poppong Trail west of the Putty Road in 2007, approximately 4 km south of the Wollemi boundary but near to other known locations east of the Putty Road. This collection was briefly referred to in Bell and Holzinger (2015) as falling within Wollemi but that observation was made in error as the tenure of this land is largely Crown. There is also an AVH collection falling in the Mellong area of Wollemi (MEL 0117446A, D'Aubert, December 1988), however notes with that collection provide the locality as "*Putty Road, 27.5 km N of turnoff to Putty*" and "*Growing on road embankment near roadway*". Re-projection of this record places it in the general vicinity of other collections of this taxon, including an apparent duplicate of this record (NSW 211686, D'Aubert, December 1988) and locations highlighted in Kodela and Tindale (2013). All of these collections fall outside of Wollemi and this rare taxon currently remains unknown from the reserve.

Acrophyllum australe *(A.Cunn.) Hoogland (Cunoniaceae)*

Two collection records exist for the Vulnerable (*BC Act 2016 & EPBC Act 1999*) *Acrophyllum australe* in the south of Wollemi, however both are considered erroneous. The first of these falls near the junction of Bowens Creek and the Wollangambe River, approximately 14 km north of Bilpin (NSW 248350, R. Horan, October 2003). However, collection notes advise the location to be "*1 km south on Browns Ridge trail from Bilpin to Burralow fire trail (2.9 km from Bells Line Road Bilpin via both these trails)*". There are no trails leading to or near the Wollangambe location, and both Browns Ridge Trail and Burralow Fire Trail (and Brown and Burralow Creeks) lie south of Bilpin in the adjacent Blue Mountains National Park. A second collection (NSW 899747, W.A. Cherry, December 1991) falls at Mountain Lagoon near Tootie Creek Trail in southern Wollemi, but the location given is "*Wildfire Ridge / Burralow Swamps*". Burralow Swamp forms part of Burralow Creek catchment in Blue Mountains National Park, south of Bilpin and Mountain Lagoon. *Acrophyllum australe* consequently remains unknown from Wollemi.

Allocasuarina glareicola *L.A.S.Johnson (Casuarinaceae)*

A single collection record (NSW 506318, R.L. Johnstone, December 2002) of the Endangered (*BC Act 2016 & EPBC Act 1999*) *Allocasuarina glareicola* falls near the junction of Comleroy Road and Ruins Trail, in the south-eastern corner of Wollemi. This species occurs in a highly restricted area of western Sydney, generally bounded by the suburbs of Londonderry, Windsor Downs, Shanes Park and Castlereagh, and its occurrence along Comleroy Road seems unlikely. Indeed, notes associated with the Johnstone collection state "*c. 200 m NW of the northern end of Nutt Rd, Londonderry*", placing it well within the known range of this species and not in Wollemi.

Melaleuca biconvexa *Byrnes (Myrtaceae)*

There is a single Bionet Atlas record purportedly of the Vulnerable (*BC Act 2016 & EPBC Act 1999*) *Melaleuca biconvexa* for a collection made near the Glow Worm Tunnel in the south-western corner of Wollemi. This record stems from the NSW Herbarium specimen register, with the catalogue number NSW 664310. However, on further inquiry this catalogue number actually refers to *Baeckea utilis* and not *Melaleuca biconvexa*, but the same collector and date are shown for both records (D. Crestani, January 2001). *Melaleuca biconvexa* is a small to large paperbark tree principally of low elevation swamps on the Central and South Coasts (Bell 2016, 2017b), and its occurrence so far inland and at high elevation would be highly significant.

Pterostylis nigricans *D.L.Jones & M.A.Clem. (Orchidaceae)*

A 1969 observation record (NSW 103683) in the Bionet Atlas for the Vulnerable (*BC Act 2016*) *Pterostylis nigicans* exists for an area just north of Mt Coricudgy, in the central part of Wollemi. This species normally grows on coastal sand habitats in northern New South Wales and Queensland (Jones & Clements 1988), and its presence in central Wollemi on high elevation sandstone would be highly unusual. Further investigation in the AVH reveals that this sighting record and its associated herbarium catalogue number actually refers to a spirit collection of an indeterminate *Genoplesium* sp. (NSW 103683, R.G. Coveny, March 1969), and is not a *Pterostylis*. The location notes associated with this collection, "*Middle Hill, c. 25 miles (40 km) E of Rylstone (between Mt. Corricudgy and Mt. Kerry)*", imply that the geospatial position is correct but that *Pterostylis nigricans* was not collected there, and this species therefore remains unknown from Wollemi.

Syzygium paniculatum *Gaertn. (Myrtaceae)*

Two AVH collection records (NSW 129335, L.A.S. Johnson, April 1953; NSW 280289, R. Melville, April 1953) at Kurrajong Heights (close to or just inside Wollemi) from the same gathering have been determined as the Endangered (*BC Act 2016*) *Syzygium paniculatum*. This species is primarily a coastal small tree of lower elevations, where it occurs in littoral and gallery rainforest (Payne 1991; Thurlby et al 2012). Notes with the two Kurrajong Heights collections state that they occurred "*on cleared Wianamatta shale*" and "*top of bank by roadside with* Syncarpia [laurifolia] glomulifera". These comments suggest that at the time (1953) there had already been extensive clearing at this locality, and that their occurrence likely falls outside of the current Wollemi boundary. Additionally, at least in recent times *Syzygium paniculatum* is a commonly planted species and although it is unknown if such plantings were widely undertaken 65 years ago, there remains the possibility that this specimen was not native to the area. This species therefore remains unknown from Wollemi until further clarification can be made.

Discussion

Over the past decade, a further sixteen significant vascular plant species have been newly recorded within Wollemi, or have surfaced in observation and specimen collection databases. This increases the total number of significant taxa for the reserve to 110. Under IUCN criteria, this incorporates 3 Critically Endangered, 16 Endangered, 27 Vulnerable, 4 Near Threatened, 39 of Least Concern and 21 Data Deficient (Appendix 1). Legally, 48 taxa or populations are listed as threatened under the NSW *Biodiversity Conservation Act 2016*, while 33 are similarly listed under the Commonwealth *Environment Protection and Biodiversity Act 1999*. In New South Wales, 1 taxon is listed as Critically Endangered, 19 as Endangered, 26 as Vulnerable and 2 as Endangered Populations. For Commonwealth listed taxa, 1 is listed as Critically Endangered, 9 as Endangered and 23 as Vulnerable (Fig. 12). Sixty-one taxa are currently unrepresented within either legislation and may be considered rare, while eight taxa remain scientifically undescribed. Following assessment of all newly added taxa against IUCN criteria, one currently unlisted species (*Hibbertia coloensis*) qualifies as Critically Endangered, while a second (*Bertya linearifolia*) qualifies as Endangered (see Appendix 1).

Taxonomy is a slow-moving science with new collections of novel entities regularly being found but official descriptions often taking many years or decades to finalise. It is therefore not surprising that new taxa and revisions to existing taxonomic groups result in additions to the flora of an area. Many newly described taxa are yet to be formally assessed for conservation status, and for new entities extracted out of species complexes it is difficult to determine their status when previous confusion with related species impacts on identification. For example, *Hibbertia pustulata* was formerly part of the *Hibbertia rufa* complex and occurs in both Blue Mountains and Wollemi National Parks, but is restricted to swampy habitats which are not widespread across the landscape (Toelken & Miller 2012). There is currently insufficient information and collections for this taxon to determine how significant it is, particularly given previous confusion with other species in the '*rufa*' group. Similarly, the rare *Epacris browniae* has been recently described for populations growing at high elevation in the Blue Mountains area (Coleby 2015), and although records exist close to Wollemi none have yet been located within this reserve, perhaps due to confusion with other more common epacrids.

A decade on from the last assessment of significant species, Wollemi National Park remains an important conservation reserve for the protection of a wide array of plant species and their habitats. The 110 taxa detailed here is an impressive number, yet this quantum is unlikely to be exhaustive. Eight of the forty-two significant taxa listed in Bell (2008) as potentially occurring within Wollemi have now been confirmed for the reserve. More of the remaining thirty-four potentially still occur there but await fortuitous discovery by keen bushwalkers and botanists. Other taxa not currently recognised as rare or threatened may also be added to this list: the inclusion of *Bertya linearifolia* and *Hibbertia coloensis* in this paper as significant taxa is based solely on the paucity of collections and observations (<5 of each) within AVH and Bionet Atlas databases. There will inevitably be further poorly collected taxa like these that currently 'slip under the radar' of threatened species assessments, and it may not be until they are formally assessed and legally protected that their presence in Wollemi will be noted.

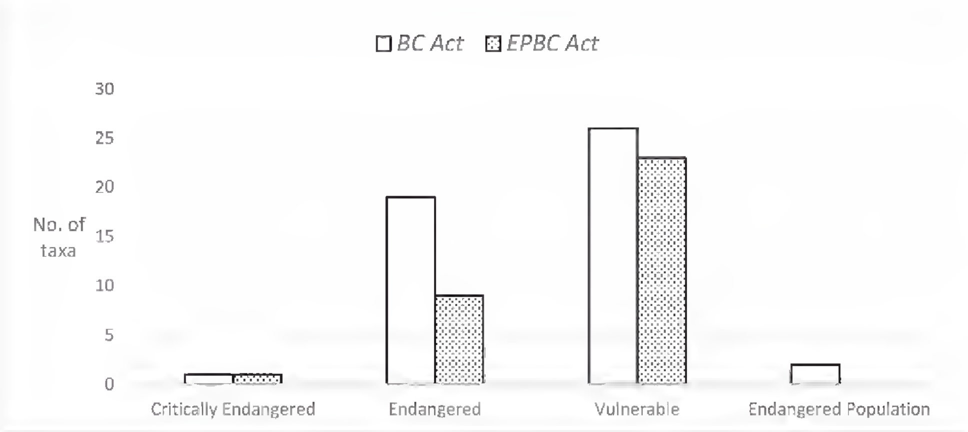

Fig 12. Summary of legally protected taxa known from Wollemi National Park.

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Appendix 1 Significant vascular plants known from Wollemi National Park showing threatened species conservation codes

IUCN codes are as documented in Bell (2008), except for newly discussed taxa (marked *) which have been assessed against IUCN (2017) guidelines. Entries shown within '[ ]' are pre-existing codes from the literature; all others are newly applied here.

Taxon	IUCN Category	EPBC Act	BC Act	ROTAP code
Critically Endangered CR				
Wollemia nobilis	[CR D]	CE	CE	[2ECit]
Eucalyptus sp. '*Howes Swamp Creek'* (Doherty 26)	CR D1	E	E	[2ECi]
**Hibbertia coloensis*	CR B1ac; B2ac; C2a			2EC-
Endangered EN				
Zieria involucrata	EN A1a; B1ac	V	E	[2VCa]
Macrozamia elegans	EN A2ad			[2VC-]
**Senecio linearifolius* var. *dangarensis*	EN A2a; B1ac		E	2EC
**Bertya linearifolia*	EN B1ac; B2ac; D1			[2E]
Persoonia hirsuta var. *evoluta*	EN B1ac	E	E	[3KCi]
Persoonia marginata	EN B1ac	V	V	[2V]
Pimelea curviflora var. *curviflora*	EN B1ac	V	V	[2VC-]
Pultenaea sp. (Olinda)	EN B1ac		E	[2EC-]
**Commersonia rosea*	EN B2ac	E	E	[2E]
**Monotaxis macrophylla*	EN B2ac		E	3VC
**Pomaderris queenslandica*	EN C2a		E	[3VCi]
Asterolasia elegans	EN C2b	E	E	[2ECa]
Baeckea kandos	EN D1	E	E	[2RC-t]
Gyrostemon thesioides	EN D1		E	[2EC]
Haloragodendron gibsonii	EN D1			[2RCat]
Pomaderris sericea	EN D1	V	E	[3VCi]
Vulnerable VU				
Acacia pubescens	VU A2bc	V	V	[3VCa]
**Dillwynia tenuifolia*	VU B1ac		V	[2RCa]
Ozothamnus tesselatus	VU B1ac	V	V	[2VC-]
Olearia cordata	VU B1ac; C2b	V	V	[2VCi]
Velleia perfoliata	VU B2ac; D1	V	V	[2VC-]
**Grevillea parviflora* subsp. *parviflora*	VU C2a	V	V	3VC
**Homoranthus darwinioides*	VU C2a	V	V	[3VCa]
Melaleuca deanei	VU C2a	V	V	[3RC-]
Melaleuca groveana	VU C2a; D2		V	[3RC-]
**Eucalyptus fracta*	VU D1		V	[2R-]
Pomaderris precaria	VU D1			[2VC-; 2EC-]
Grevillea obtusiflora subsp. *obtusiflora*	VU D1+2	E	E	[2E]
Leptospermum spectabile	VU D1+2			[2RC-; 2RCt]
Cynanchum elegans	VU D2	E	E	[3ECi]
Epacris coriacea	VU D2			[3RC-]
Epacris muelleri	VU D2			[3RC-]
Eucalyptus aenea	VU D2			[2RC; 2RC-]
Eucalyptus bensonii	VU D2			[2RC-t]
Eucalyptus burgessiana	VU D2			[2RCa]
Eucalyptus corticosa	VU D2		V	[2VC-]
Isotropis foliosa	VU D2			[3KC-]
Leionema scopulinum	VU D2			[2RCit]
Pentachondra dehiscens	VU D2			[3RC]
Pomaderris bodalla	VU D2		V	[2R]
Prostanthera cryptandroides subsp. *cryptandroides*	VU D2	V	V	[2RC-t; 2VC-]

Taxon	IUCN Category	EPBC Act	BC Act	ROTAP code
Prostanthera discolor	VU D2	V	V	[2VC-]
Prostanthera stricta	VU D2	V	V	[2V]
Near Threatened NT				
Acacia bynoeana	NT	V	E	[3VC-]
Acacia gordonii	NT	E	E	[2K]
**Cymbidium canaliculatum*	NT		EP[1]	3RCa
Leionema sympetalum	NT	V	V	[2VC-]
Least Concern LC				
Acacia asparagoides	LC			[2R]
Acacia bulgaensis	LC			[2RC-]
Acacia flocktoniae	LC	V	V	[2VC-]
Acacia fulva	LC			[2RC-; 2RCa]
Acacia matthewii	LC			[3RC-]
Acacia subtilinervis	LC			[3RCa]
Almaleea incurvata	LC			[2RC-t; 2RC-]
Apatophyllum constablei	LC			[2EC-; 2RCa]
Atkinsonia ligustrina	LC			[2RCa]
Banksia penicillata	LC			[3RC-]
Boronia floribunda	LC			[2RC-]
Boronia fraseri	LC			[2RCa]
Boronia rubiginosa	LC			[2RCa]
Callistemon shiressii	LC			[3RC-]
Darwinia peduncularis	LC		V	[3RCi]
Eucalyptus cannonii	LC		V	[2VCi; 2RCa]
Eucalyptus fergusonii subsp. *dorsiventralis*	LC			[2RC-]
Eucalyptus hypostomatica	LC			[3RC-]
**Eucalyptus michaeliana*	LC			[3RCa]
Eucalyptus prominula	LC			[2KC-]
Gonocarpus longifolius	LC			[3RC-; 3RCa]
**Grammitis stenophylla*	LC		E	3RCa
Grevillea evansiana	LC	V	V	[2VC-; 2VCa]
Grevillea johnsonii	LC			[2RCi; 2RCa]
Grevillea montana	LC			[2KC-; 2RCa]
Homoranthus cernuus	LC			[2RCa]
Leucochrysum graminifolium	LC			[2R; 2RC-]
Lissanthe sapida	LC			[3RCa]
Lomandra fluviatilis	LC			[3RCa]
Olearia quercifolia	LC			[3RC-]
**Philotheca ericifolia*	LC	V		[3RC-]
Philotheca obovalis	LC			[3RCa]
Platysace clelandii	LC			[2RCa]
Prostanthera hindii	LC			[2KC-]
Pseudanthus divaricatissimus	LC			[3RCa]
Rulingia hermanniifolia	LC			[3RCa]
Rupicola ciliata	LC			[2RC-t]
Rupicola decumbens	LC			[2RC-]
Tetratheca glandulosa	LC		V	[2VC-]
Data Deficient DD				
Blechnum gregsonii	DD			[2RCa]
Boronia barkeriana subsp. barkeriana	DD			[2RC-]
Brasenia schreberi	DD			[3RC-+]
Cyphanthera scabrella	DD			[2RC-]

Taxon	IUCN Category	EPBC Act	BC Act	ROTAP code
Diuris sp. aff. *punctata* (Colo River)	DD			[2KC]
Eucalyptus gregsoniana	DD			[3RCa]
Eucalyptus expressa	DD			[3KC; 2KC]
Kennedia retrorsa	DD	V	V	[2VCa; 2VCi]
Leionema lamprophyllum subsp. *orbiculare*	DD			[2R-]
Leionema sp. 'Colo River' (Weston 2423)	DD			[2VC-]
Pomaderris brunnea	DD	V	E	[2VC-]
Pomaderris pauciflora	DD			[3RC-]
Pomaderris sp. aff. *nitidula (*Glen Gallic)	DD			[2KC]
**Prostanthera cineolifera*	DD	V	V	[2K]
Prostanthera stenophylla	DD			[2KC-]
Prostanthera sp. aff. rotundifolia. (Mt Iris)	DD			[2KC-]
Pultenaea glabra	DD	V	V	[3VCa]
**Pultenaea 'monticola'* Mt Irvine	DD			2KC
Rulingia sp. aff. dasyphylla (Goulburn R. Valley)	DD			[2KC]
Seringia denticulata	DD		EP^{2}	[3RC-]
Swainsona recta	DD	E	E	[3ECi]

EP^{1} = Endangered Population in the Hunter catchment
EP^{2} = Endangered Population in Hawkesbury local government area

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A Preliminary Checklist of Flower-visiting Insects from *Syzygium floribundum, Syzygium smithii* and *Tristaniopsis laurina*: three members of the Myrtle Rust-vulnerable plant family Myrtaceae.

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***Abstract*:** Insects visiting flowering trees of *Syzygium floribundum, Syzygium smithii* and *Tristaniopsis laurina* (Myrtaceae) were recorded in lowland subtropical rainforest communities in the Manning Valley, mid-north coast of New South Wales. These species are visited by a taxonomically broad assemblage of insects, many of which are known to frequent other rainforest- and open forest- flowering plant species. Consequently there is likely to be a regional pool of potential pollinators found throughout the range of each plant.

Key Words: *Syzygium floribundum, Syzygium smithii, Tristaniopsis laurina,* Myrtaceae, endangered ecological communities, subtropical rainforest, wet sclerophyll forest, pollination, anthophilous insects, Myrtle rust, *Austropuccinia psidii*, extinction events.

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Introduction

Despite the historical interest in the conservation, ecology and diversity of Australia's subtropical rainforests (Adam, 1987, 1992, Floyd, 1990, Werren & Kershaw, 1987, Williams, 1993, 2002, 2003, Kitching *et. al.*, 2010) relatively little is known about the ecological relationships between individual plant species and their associated biota; not least with their potential pollinators (Williams & Adam, 2010, 2013). When extinction events occur, as is threatened for Australian Myrtaceae by the introduced Myrtle rust fungus *Austropuccinia psidii* (NSW Scientific Committee, 2017, Makinson, 2018a, 2018b), the consequent lack of knowledge of basic interactions between species makes it difficult to adequately formulate recovery action plans or predict any secondary outcomes.

The purpose of this paper is to provide an overview of the known diversity of the insect fauna that frequents mass-flowering *Syzygium floribundum* (F. Muell.) B. Hyland, *Syzygium smithii* (Poiret) Merr. and Perry and *Tristaniopsis laurina* (Smith) Peter G. Wilson and Waterhouse (Myrtaceae) trees in subtropical rainforest; and from which a suite of pollinators may be recruited. We do not claim it is exhaustive, for no sampling regime, regardless of how temporally or spatially extensive, is likely to account for *all* possible associated anthophilous insects, regardless of their degree of behavioural or morphological adaptation to the role. Minute and certain 'rare' species will be consistently overlooked. Nevertheless the records tabled here (Table 1) represent a species list not otherwise collectively available, and in many instances unpublished. It is hoped that this will contribute to a better understanding of the interacting invertebrate biota and encourage additional investigation of the reproductive ecology of Australia's subtropical rainforest myrtaceous flora in advance of any further Myrtle rust pathogen impacts.

Study Species, Sites and Methods

The investigation of anthophilous insect-flower relationships of *Syzygium floribundum, Syzygium smithii,* and *Tristaniopsis laurina* was part of a much larger study of the reproductive ecology and flowering phenology of lowland (i.e. <600m elevation) subtropical rainforest remnants undertaken from 1990 to 1994 (Williams, 1995, see also Williams & Adam, 1995, 1997, 1998, 1999a, 1999b, 2001, Williams *et al.,* 2001, Adam & Williams, 2001); within which these three species constitute a small subset. Records acquired from this have been supplemented by additional later studies of subtropical rainforest plants (Williams, 1998, Williams & Walker, 2003), as well as casual field observations of general subtropical rainforest insect-plant relationships that have continued to this day. Collectively over this period, field investigation amounted to many hundreds of hours. Statistical analyses and interpretation of the 1990-1994 study data (resulting from the collection, sorting and identification as morphospecies/recognizable taxonomic units [RTUs] of more than 60,000 insects representing >100 families and >500 genera) are given in Williams (1995).

The study sites are situated within the Manning Valley (approx. 31°52' S, 152°52' E) on the mid-north coast of New South Wales, and comprise rainforest communities variously listed as *Endangered Ecological Communities* under New South Wales State (*Biodiversity Conservation Act 2016*) and Federal (*Environmental Protection and Conservation Act 1999*) legislation. An overview of the extent of rainforest and its associated biota, within the Manning Valley, is given in Williams (1993). Harrington (32°52'30" S, 152°41'00" E) and Manning Point (31°53'30" S, 152°40'00" E) are littoral rainforest remnants located immediately north and south of the northern opening of the deltaic Manning River estuary. Lansdowne Nature Reserve (31°47'30" S, 152°32'30" E) is a small floodplain remnant located near Lansdowne village, and Wingham Brush Nature Reserve (31°52'40" S, 152°31'30" E) is located on the banks of the Manning River adjacent to Wingham township. Lorien Wildlife Refuge (31°45'00" S, 152°32'30" E) is situated north of Lansdowne village, forming part of the Lansdowne-Comboyne Escarpment, and includes both rainforest and eucalypt-dominated wet sclerophyll forest formations. Woko National Park (31°49'00" S, 151°47'00" E) is located further inland, northwest of Gloucester; the distinctive riparian (rheophytic) small-leaved form of *Syzygium smithii* (Harden *et al.* 2006) occurring there providing a comparison to the same species in sites situated to the east.

Syzygium floribundum (Fig. 1), *Syzygium smithii* (Fig. 2.) and *Tristaniopsis laurina* (Fig. 3) are small to medium-sized trees (Harden, 1991) commonly found growing in the region on forest margins. However, *Syzygium floribundum* is normally restricted to the riparian zone of lowland freshwater streams where it may constitute the dominant canopy species. *Tristaniopsis laurina* also can be encountered alongside streams as a dominant canopy-forming tree, but usually at slightly higher elevations where it may form narrow 'gallery' rainforests. The flowers of *Syzygium floribundum* and *Syzygium smithii* are coloured white to creamish-white, those of *Tristaniopsis laurina* are bright yellow. *Syzygium floribundum* produces very prominent bright red juvenile leaf flushes but this generally does not overlap with flower production. Annual flowering patterns vary slightly during spring and summer months, and some populations have failed to flower during drought conditions (Williams, 1995, G. Williams pers. obs.). There is only minor overlap in some seasons with flowering events. All produce copious quantities of nectar. The three species conform to the 'general entomophilous' flower structure in which individual flowers are small with little depth effect in the corolla, normally do not possess nectar guides, and are actinomorphic in form allowing entry by numerous ecologically-unspecialised flower visiting insects (Faegri & van der Pijl, 1979, Williams & Adam, 2010, Willmer, 2011).

Information about floral characteristics of the three species is given below.

Floral descriptions of plant species.

Syzygium floribundum (F. Muell.) B. Hyland (Fig. 1.)

Flowers are bisexual but generally self-incompatible (Adam & Williams, 2001), numerous and in panicles, exposed and massed, rarely obscured by foliage. Flower presentation is similar to that in *Eucalyptus* spp. Flowers white or creamish-white, strongly and sweetly scented like honey. Number of petals not recorded. Receptacle diameter approximately 3mm, corolla (stamen 'brush') diameter 12-14mm. Stamens numerous, long, free, variable in length (3-8mm). Anthers dehiscent at flower opening. Ovary ½ inferior. Stigma narrow, pointed, at end of long style and appears receptive at flower opening. Freshly open flowers do not possess nectar. Stamens readily absciss following pollination. Exine sculpture indistinct-smooth (Williams & Adam, 1999). Mean flower longevity 6 (range 4-8) days (Williams, 1995). Distribution: Williams River, New South Wales to Mackay, Queensland (Floyd, 1989).

Syzygium smithii (Poiret) Merr. and Perry (Fig. 2.)

Flowers bisexual, slightly self-compatible (Adam & Williams, 2001), exposed and massed in panicles, sparse on outer crown margin or recessed below foliage. Flowers white or creamish-white, scented without nectar guides, 3-4mm wide. Petals usually 6, these absciss on first day of anthesis. Stamens generally 2-ranked, longer outer stamens approximately 26, inner shorter stamens approximately 36. Stamens free, filaments approximately 10 times longer than anthers. Ovary ½ inferior, style robust, rigid, +/ shorter than stamens. Stigma small, stigmatic surface 'fleshy' in appearance, formed as an apical extension/continuum of the style rather than as an obviously discrete surface or structure. Flowers protogynous, stigma appears receptive at flower opening. Anther dehiscence sequential, longer outer rank dehisce first, inner shorter rank dehisce later, generally following loss of stigma receptivity and during initial flower senescence. Pollen white, sticky. Exine sculpture indistinct-smooth (Williams & Adam, 1999). Nectar not present in unopened flowers, but present on or shortly after flower opening as discrete droplets on surface of hypanthium. Partly chewed flowers still produce nectar. Flower opening sequential, diurnal, mean floral longevity 6 (5-7) days (Williams, 1995). Distribution: Wilsons Promontory, Victoria to Bundaberg, Queensland. (Floyd, 1989).

The small-leaved form of *Syzygium smithii* is normally associated with river flats and streams. Flowering episodes are distinctive in that flowers on individual trees are massed and prolific, rather than the frequently sparse and obscured (by foliage) flowers produced by typical *S. smithii*.

Tristaniopsis laurina (Smith) Peter G. Wilson and Waterhouse (Fig. 3.)

Flowers bisexual but self-incompatible (Adam & Williams, 2001), in small cymes, massed but partially obscured by foliage. Flowers strongly scented, honey-like. Corolla diameter 11-5mm (hypanthium 6mm). Petals and stamens bright yellow, receptacle and sepals yellowish-green. Petals 5, and absciss in senescent stage. Stamens fused into 5 antepetalous cluster, each cluster possessing approximately 21 stamens. Stamens variable in length, fused staminal clusters shed as a unit on abscission. Anthers small. Ovary ½ inferior. Hypanthium pentangular, inner surfaces slightly convex, basal nectiferous gland granulose. Style long and retained in infructescent stage. Pollen slightly sticky, exine sculpture indistinct-smooth (Williams & Adam, 1999). Mean flower longevity 5 (range 4-6) days. Receptacles that have shed perianth segments do not produce nectar. Distribution: Bairnsdale, Victoria to Eumundi, Queensland (Floyd, 1989).

Collection of insects visiting *Syzygium floribundum, Syzygium smithii* and *Tristaniopsis. laurina* inflorescences was undertaken throughout the flowering seasons (between October – February). Details of flowering events, flower presentation, sampling dates, sample sizes and composition, and the days on which individual insect species were collected on each plant species are given in Williams (1995).

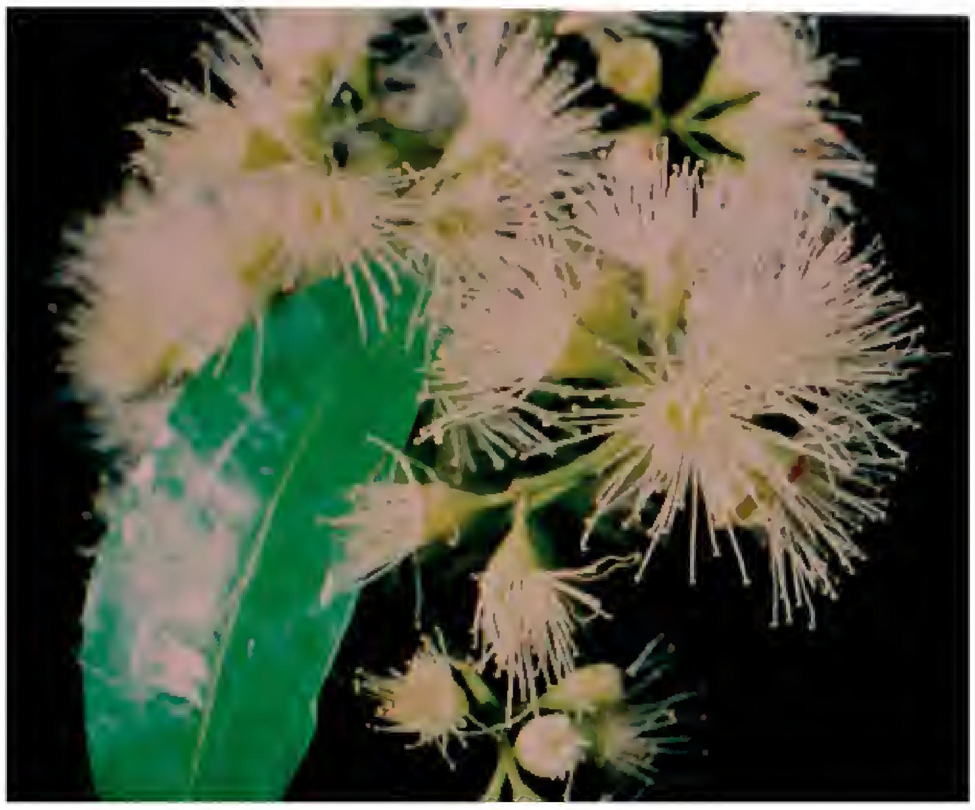

Fig. 1. *Syzygium floribundum.*

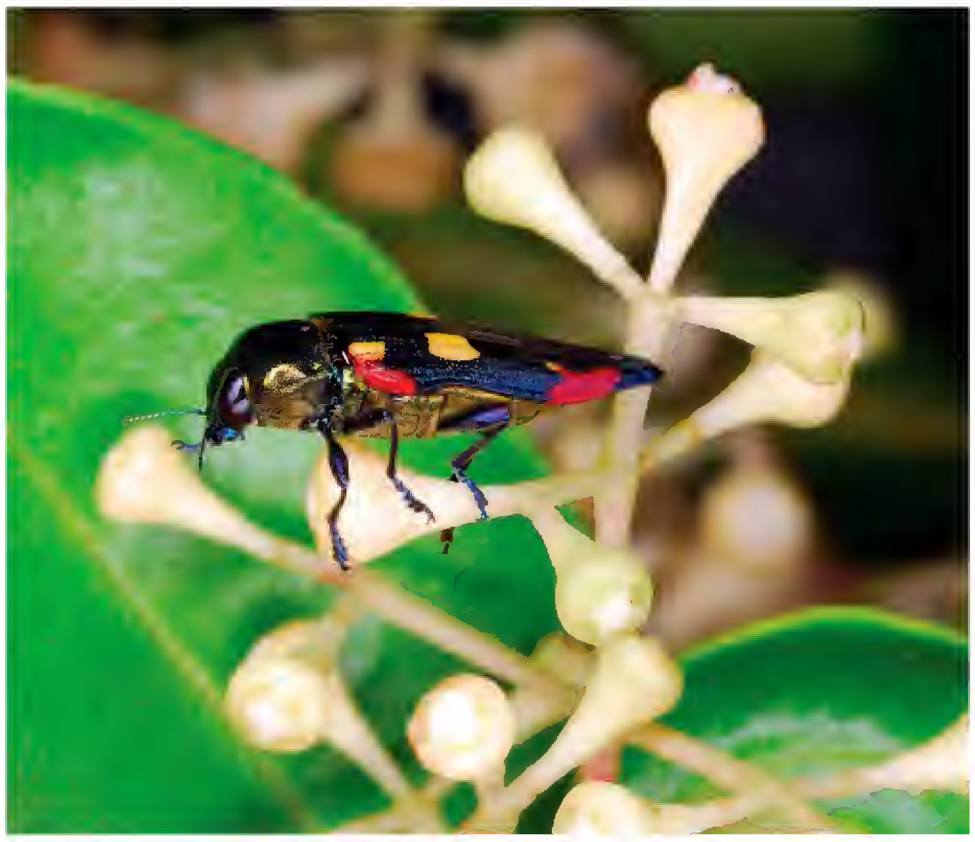

Fig. 2. *Syzygium smithii* with *Castiarina producta* (Buprestidae). (photo credit Allen Sundholm)

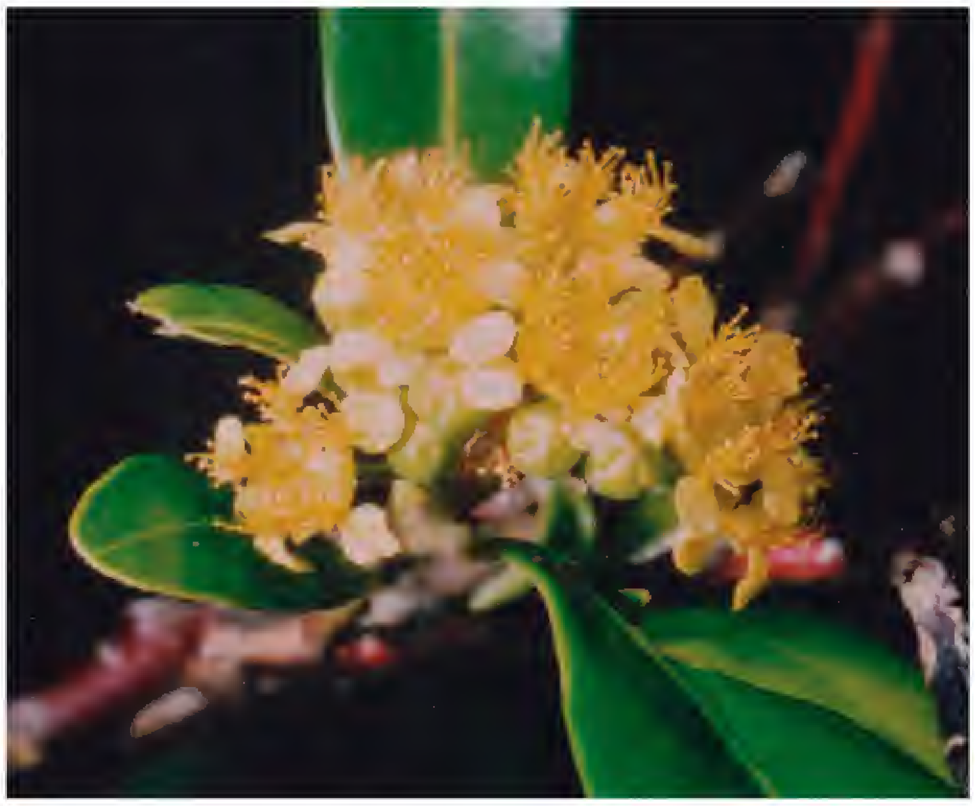

Fig. 3. *Tristaniopsis laurina.*

During daily field work it was observed that sudden events of intermittent cloud cover, or a seasonally atypical drop in temperature, resulted in immediate reduction (often complete absence) of insect activity. Moderate-heavy rainfall resulted in the washing (or dilution) of nectar from inflorescences, and was followed by marked reduction for several days in insect abundance and diversity. Thus sampling was only carried out on consistently sunny, warm (>25° C.) days. Equally, during excessively hot (>35° C.) times insect activity also dropped dramatically, and for this reason samples were only collected morning and afternoon when extremes of heat had yet to arise or had abated. Independent of environmental influences large mobile flower-frequenting insects, such as cetoniid beetles, butterflies and eumenine wasps, occurred in much fewer numbers, and so their presence at individual inflorescences was usually infrequent over hourly scales of time.

Flower visiting insects were either hand-netted individually, or mass sampled by quickly placing a net over individual flower masses and vigorously shaking; the net mouth being closed by rotating the handle to minimise loss of fast flying insects. The net was then detached from the handle, placed in a plastic container, sprayed with commercial pyrethroid insecticide and sealed. After 10-20 minutes the contents were then emptied into individually labelled containers for later sorting, measurement and identification (Williams, 1995). This technique was used to acquire the data presented in Appendix 1 (as well as the more extensive data set in Williams, 1995), and allowed the collection of most insects frequenting inflorescences at the sampling times (between 9 am to 3 pm), but inevitably this resulted in collecting some specimens (e.g., Dolichopodidae) associated with foliage rather than flowers; the distinction based on familiarity with taxa from many years of field experience and observation, discussions with colleagues, and extensive reference to the entomological literature for known, principally foliage-eating, groups such as Orthoptera, Lepidoptera larvae and various Coleoptera (especially Chrysomelidae and certain Buprestidae). Later sorting established that these were minimal in abundance and diversity. This supports the findings of Wardhaugh *et al*. (2013) that there may be little overlap of species between different rainforest microhabitats. Voucher specimens were placed with the Australian Museum (Sydney) with a subset held in the field reference collection at Lorien Wildlife Refuge (Lansdowne). However, all the microhymenoptera and Thysanoptera material was deposited with the Australian National Insect Collection (Canberra). Detailed data records, including field notes, from the 1990-1994 study remain with the senior author.

Table 1. Preliminary checklist of insects collected from mass-flowering *Syzygium floribundum, Syzygium smithii* and *Tristaniopsis laurina.*

Key: Records given as single '1' presence scores for species, actual number of species indicated in cells where determinations beyond genus are uncertain. '?>1' = single species or more than 1 species present. 'sp./spp.' = 1 or more species may be present in row. Undetermined genera clumped as 'undet. sp./spp.', with number of species given in cell. '*' = placed after family indicates included species generally strongly or partly adapted to a floricolous habit, '+' indicates incidental non-anthophilous species. Anthophilous relationship for family not indicated where species are either poorly adapted, or plant interaction is uncertain or included species are likely incidental visitors. '#' = large species observed to undertake long distance inter-plant movements.

Plant species.
1. *Syzygium floribundum*
2. *Syzygium smithii*
3. *Syzygium smithii* small leaf form
4. *Tristaniopsis laurina*

Sites
A. Harrington.
B. Manning Point.
C. Lansdowne Nature Reserve.
D. Lorien Wildlife Refuge (rainforest).
E. Lorien Wildlife Refuge (wet sclerophyll forest).
F. Wingham Brush Nature Reserve.
G. Woko National Park.

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
BLATTODEA								
Ectobiidae								
Ellipsidion sp.							1	
Gisternia australis							1	
undet. sp./spp.							1	
COLEOPTERA								
Aderidae								
Aderus spp.	2	1					1	1
?Aderidae								
undet. sp.	1							
Anobiidae								
undet. sp.	1							
Anthicidae *								
Anthicus sp./spp.	1	?>1	1	1	1			1
Egestriomima albolineata						1		1
Egestriomima ?albolineata		1						
Egestriomima sp. nr. *griseolineata*		1				1		
Egestriomima sp.						1		
Macratia ?analas		1						
Macratia victoriensis		1						
Attelabidae								
Auletobius sp.	1							

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
?*Euops* sp.			1					
Belidae								
Belus tenuis								1
Boganiidae								
Athertonium sp. nov.		1			1	1		
Buprestidae *								
Calodema regale #							1	
Castiarina acuminata								
Castiarina alternecosta	1					1		
Castiarina amplipennis						1		
Castiarina analis	1							
Castiarina australasiae	1							
Castiarina beatrix	1							
Castiarina bella	1							
Castiarina brutella	1							
Castiarina decemmaculata				1				
Castiarina deliculata	1							
Castiarina delta	1					1		1
Castiarina gentilis					1			
Castiarina harrisoni	1							
Castiarina humeralis	1							
Castiarina insignis	1	1			1			1
Castiarina kanangara	1							
Castiarina liliputana	1	1				1		1
Castiarina luteipennis	1							
Castiarina maculipennis	1							
Castiarina minuta		1				1		1
Castiarina oblita	1							
Castiarina octospilota	1							
Castiarina praetermissa	1							
Castiarina producta	1	1			1	1	1	1
Castiarina pulchripes						1		
Castiarina rufipennis						1		
Castiarina scalaris	1							
Castiarina ?*sexcavata*		1				1		
Castiarina sexguttata		1				1		1
Castiarina sp. nr. *spectabilis*	1							
Castiarina spinolae	1							
Castiarina sulfurea	1							
Castiarina tyrrhenia	1							
Castiarina undulata	1							
Castiarina variegata	1							
Castiarina ?*vicina*		1						
Castiarina warningensis	1							
Castiarina williamsi	1	1						
Diphucrania sp.						1		
Maoraxia aureoimpressa +					1			
Melobasis splendida +		1						
Melobasis sp. +								1
Metaxymorpha grayi #	1						1	
Neocuris ?*coerulans*						1		
Neocuris spp.						2		
Pseudanilara cupripes		1						
Selagis aurifera		1						
Selagis splendens	1	1				1		
Torresita cuprifera	1	1						
Cantharidae *								
Chauliognathus flavipennis				1	1	1		1
Chauliognathus inconstans		1						

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Chauliognathus lugubris						1		
Chauliognathus sp.			1					
Heteromastix spp.		1		2	1	1	1	1
Pseudananca sp./spp.	1							
Selenurus sydneyensis	1	1		1	1		1	1
Carabidae								
Amblytelus amplipennis			1					
Sarcothrocrepis sp.		1						
Cavognathidae								
Cavognatha sp.			1					
Cerambycidae *								
Arideus thoracicus #		1				1	1	1
Ceresium australe +		1						
Demonisis spp.		1			2	2		1
Distichocera superba #	1	1					1	
Earnis sp./spp.						1		1
Eroschema poweri		1						
Hesthesis sp. nr. *bizonata*							1	
Oroderes sp.						1		
Psilomorpha ?*apicalis*		1						
Psilomorpha divisus						1		
Psilomorpha tenuipes		1						
Psilomorpha ?*tenuipes*					1			
Pytheus sp./spp.		1				1		
Stenocentrus ostricilla		1	1					
Stenocentrus ?*ostricilla*		1				1		
Stenocentrus suturalis						1		
Syllitus sp./spp.	1		1		1	1		1
Iphra ?*moestula* +				1				
Titurius intonsodorsalis					1			
Tragocerus spencei #	1							
Tropocalymma dimidatum			1					
Chrysomelidae								
Aporocera iridipennis								1
Aporocera ?*iridipennis*		1						
Ceratia hilaris						1		
Crepidodera sp./spp.		1		1	1	1		
Ditropidus concolor		1						
Ditropidus sp. nr. *lentulus*	1	1						1
Ditropidus sp./spp.		1	1					
Edusella glabra					1			
?*Edusella* spp.							2	
Monolepta australia	1	1			1		1	1
Monolepta sp. nr. *cognata*		1		1				1
Monolepta miniuscula			1					
Monolepta sp. nr. *miniuscula*	1			1				1
Monolepta spp.	7	3		1		2	3	1
Pepila sp.		1						
Poneridia mastersi		1						
Pyrgo complicata						1		
Rhyparida sp.				1				
?*Rhyparida* sp.nr. *satelles*						1		
?*Rhyparida* sp.						1		
Clambidae								
Clambus sp.			1					
Cleridae *								
Cleromorpha novemguttata						1		
Elaele pulchra		1					1	
Elaele sp. nr. *viridicollis*	1	1			1	1		1

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Lemidia concinna	1							
Lemidia pictipes		1			1	1		
Lemidia ?pictipes	1							
Lemidia sp. nr. *purpurea*	1							
Lemidia sp.		1						
Phlogistus conspiciendus					1	1		
Phlogistus ?erimita						1		
Phlogistus sp. nr. *erimita*		1						1
Phlogistus eximus		1			1			1
Phlogistus ?eximus						1		
Phlogistus plutus						1		
Phlogistus sp./spp.				1	1			
Scrobiger splendidus	1					1		
Tarsostenodes simulator	1	1			1			
Zenthicola australis						1		
Zenthicola funestus						1		
Coccinellidae								
Archegleis edwardsi						1		
Coccinella repanda		1						1
Coccinella ?repanda	1	1						1
Diomus notescens	1	1						1
Epilachna spp.		2						1
Halmus chalybeus		1				1		
Harmonia testudinaria							1	1
Micraspis frenata					1			
Rhizobius sp./spp.			1					1
?*Rhizobius* sp.	1							
?*Scymnus* spp.		1			1	1		1
Corylophidae								
Ortopterus sp.	1							
Sericoderus spp.	2	1	1		?>1	?>1	1	1
Cryptophagidae								
Anichera lewisi		1						
Curculionidae								
Baris angophorae	1						1	1
Cyttalia sydneyensis	1	1			1	1		1
Cyttalia ?sydneyensis							1	
Eristinus eucalypti		1						
Haplonyx spp.	1	2						
?*Ipsichroa* sp.		1						
Meriphus spp.			2	1		2		
Neomelanterius carinicollis				1	1			
Orthorhinus sp.					1			
Storeus spp.			2		1	2		1
Tychiini spp.		4	2	1	1	2		1
undet. spp.	1	1			1			2
Dermestidae								
Anthrenocerus spp.	1	?>1	2	1				>1
?*Anthrenocerus* sp./spp.				1	1		1	
Orphinus sp.		1						
Trogoderma ?froggati				1				
Trogoderma spp.		1	1	2				
?*Trogoderma* spp.	2	2						
Elateridae *								
Anilicus sp.							1	
Drymelater aulacoderus						1		
Drymelater ?aulacoderus		1						1
Drymelater australis						1	1	
Drymelater ?australis		1						1

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Drymelater basalis					1			
Drymelater ?basalis		1						1
Drymelater sp./spp.					1	1		
?*Lacon* sp.							1	
Microdesmes angulatus			1		1			
Microdesmes collaris				1		1		
Microdesmes ?collaris					1			
Microdesmes pubescens	1					1		
Megapenthes futilis	1	1			1	1	1	1
Melanoxanthus lativittis	1							
Ophidius histrio #	1						1	
Paracardiophorus bicolor						1		
undet. sp.								1
Latridiidae								
Aridius sp.			1					
?*Bicava* sp.			1					
Corticara japonica		1						
Cortinicara spp.	1	1	1		1	1	1	3
Lycidae *								
Metriorrhynchus ?lateralis					1			
Metriorrhynchus rhipidius						1		
Metriorrhynchus spp.		?>1	2	1		?>2		1
Melyridae *								
Balanophorus ?rhagonychinus		1						
Balanophorus sp./spp.		1				1		
?*Balanophorus* sp./spp.	1	1						
Carphurus sp.								1
Dastyes sp./spp.	1							1
Dicranolauis ?cinctus						1		
Helcogaster spp.	2	3			?>1	2	1	2
Neocarphurus ?angustibasis						1		1
Neocarphurus sp.			1					
Mordellidae *								
Mordella humeralis		1				1		
Mordella sydneyana								1
Mordella spp.	>1	>1	2	2	>1	?>2	1	>1
Mordellistena spp.	2	1	1		1		1	1
Tomoxia sp./spp.						1		1
Mycteridae								
?*Trichosalpingus* sp.						1		
Nitidulidae *								
Aethina sp./spp.	1	1						
Epuraea eyrensis					1			
Epuraea ?ocularis				1	1			
Epuraea uniformis					1	1		
Epuraea sp./spp.	1	1				1		1
?*Epuraea* sp.	1							
Notobrachypterus sp./spp.		1	1			1		
Oedemeridae *								
Copidita ?pachymera	1							
Ischnomera sp.	1							
?*Ischnomera* spp.	2	1						
Pseudolycus haemorrhoidalis						1		
Pseudolycus spp.	2	1					1	1
Sessinia nigronotata		1						
Phalacridae								
Litochrus ?maculatus	1	1					1	1
Litochrus sp./spp.			1	1	?>1			
?*Litochrus* spp.		>1	2		1			?>1

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Olibroporus spp.			3					1
?*Olibroporus* sp.				1				
Phalacrinus ?*corruscans*		1						
?*Phalacrinus* sp./spp.	1		1					
?*Phalacrus* sp.		1						
undet. sp.								1
Pselaphidae								
?*Eupines* sp./spp.	1	1						
Pyrochroidae								
Paromarteon constans					1			
?*Paromarteon* sp.	1							
undet. spp.		2						
Ripiphoridae								
Macrosiagon sp.	1							
Pelecotomoides sp.	1	1						
Salpingidae								
?*Lissodema* sp.								1
Scarabaeidae *								
- Melolonthinae								
Anthotocus ?*fugitivus*							1	
Anthotocus luridus							1	
Automolius ?*poverus* +							1	
Automolius sp. nr. *valgoides* +			1					
Cheiragra ruficollis		1	1	1		1		
Diphucephala pygmaea +	1	1						
Diphucephala ?*sericea* +						1		
Diphucephala sp.		1						
Phyllotocus australis			1					
Phyllotocus macleayi		1						
Phyllotocus marginipennis		1				1		
Phyllotocus ?*marginipennis*		1						1
Phyllotocus navicularis		1				1		1
Phyllotocus ruficollis					1			
Phyllotocus ?*ruficollis*						1		
Phyllotocus scutellaris		1			1	1		1
- Cetoniinae #								
Aphanasthes gymnopleura	1						1	
Chondropyga dorsalis	1						1	
Eupoecila australasiae	1	1					1	1
Glycyphana brunnipes							1	
Neorrhina ?*octopunctata*							1	
Neorrhina punctata	1	1				1	1	1
Schizorhina atropunctata	1							
Storeyus fasciculatus	1							
- Rutelinae								
Repsimus ?*aeneus* +		1						
- Valginae								
Microvalgus nigrinus	1							
Microvalgus ?*squamiventris*					1			
Microvalgus vagans	1				1			
Scraptiidae								
Scraptia spp.	1	2				1		
Staphylinidae								
Anotylus sp.		1						
?*Leucocraspedum* sp.								1
?*Myllaena* sp./spp.					1			1
?*Oedichirus* sp.					1			
?*Tachinus* sp.		1						
undet. spp.	?>1	>1						3

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Tenebrionidae								
- Alleculinae *								
Aethyssius fuscus						1		
Aethyssius ochracea						1		
Aethyssius pallida							1	
Aethyssius pascoei		1			1		1	
Aethyssius viridis	1							
Aethyssius ?*viridis*						1	1	
Aethyssius sp. nr. *viridis*						1		
Aethyssius sp.						1		
Atoichus sp.				1				
DIPTERA								
Acroceridae								
Ogcodes sp.		1						
Bibionidae								
Bibio imitator		1				1		
Bombyliidae *								
Geron spp.	2	1	2	1		1	2	
undet. sp.						1		
Calliphoridae *								
Amenia chrysame			1					
Amenia sp.							1	
Calliphora hillii					1			
Calliphora sp.				1				
Chlororhinia exempta	1							
Lucilia sp.		1						
?*Lucilia* sp.		1						
Paramenia sp.			1					
Stomorhina spp.	1	>1				1		2
undet. sp.								1
Cecidomyiidae								
undet. sp.	1							
?Ceratopogonidae								
undet. sp.		1						
Chironomidae								
undet. sp./spp.		1	1					
Chloropidae								
Apotropina sp.			1					
undet. sp.		1						
?Chloropidae								
undet. sp.	1							
Conopidae *								
Microconops sp.						1		
Culicidae								
undet. sp.	1							
Dolichopodidae								
?*Austrosciapus* sp.		1						
Krakatauia macalpinei			1	1				
Drosophilidae								
Drosophila flavohirta		1						
Drosophila spp.	1	?>1	1				2	1
Scaptomyza australis	1	1						
Empididae								
Hemerodromia sp.		1						
undet. spp.	2	3			1		?>2	>1
Lauxaniidae								
Homoneura sp.		1						
Melanina spp.	1	2		1	1		2	
?*Melanina* sp./spp.	1	1						

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Sapromyza ?nigriceps				1				
Sapromyza sp./spp.		1	1				1	
?*Sapromyza* spp.	2	1	1					
Steganopsis melanogaster	1	1		1		1		
Steganopsis ?melanogaster								1
?*Tephritisoma* sp.		1						
Trypetisoma sp./spp.					1	1		
?*Trypetisoma* sp.							1	
Muscidae								
Musca sp./spp.		1						1
?*Musca* sp.							1	1
Mycetophilidae								
undet. sp.	1							
Nemestrinidae *#								
Trichophthalma costalis		1				1		
Trichophthalma ?punctata		1						
Phoridae								
undet. spp.	2	2	2	1			2	1
Platystomatidae								
Duomyia spp.			2					
Microepicausta sp.			1	1				
Pogonortalis doclea			1					
?Rhagionidae								
undet. sp.			1					
Scatopsidae								
?*Scatops* sp.			1					
undet. sp.			1					
Sepsidae								
Lasionemapoda hirsuta					1			1
?*Parapalaeosepsis plebeia*	1	1		1	1	1	1	
Sepsis dissimilis		1			1	1	1	1
?*Sepsis* sp.					1			
undet. sp.							1	1
Stratiomyidae								
Odontomyia sp.		1						
Syrphidae *								
Eristalinus maculatus		1						
Psilota sp./spp.	1		1	1		1	1	
?*Syrphus* sp.		1						
?*Xanthogramma* sp.		1						
Tabanidae								
Cydistomyia nigropicta		1						1
Scaptia auriflua	1							
Scaptia sp.							1	
?*Tabanus* sp.								1
Tachinidae								
?*Rutilia* sp.							1	
Senostoma ?pallidihirtum							1	
Tritaxis sp.		1						
undet. sp./spp.			1	1				
Tephritidae								
Spathulina sp. 1						1		1
Spathulina sp. 2						1		
Spathulina sp. 3		1						
?*Tephritis* sp.								1
Trupanea sp.	1							
Therevidae								
undet. sp.								1

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Tipulidae								
undet. sp.			1					
HEMIPTERA								
Cicadellidae								
Ishidaella angustata						1		
undet.sp.							2	
Flatidae								
Siphanta ?acuta								1
Siphanta sp.			1					
undet. sp.						1		
Lygaeidae								
Arocatus sp. 1				1	1	1		
Arocatus sp. 2					1	1		
Arocatus sp. 3		1						
Membracidae								
Pogonella bispinus								1
Miridae								
Felisacus sp.						1		
undet. spp.	4	5	1					1
Orsillidae								
Nysius sp./spp.	1	1	1					
Pentatomidae								
undet. sp.		1						
Psyllidae								
undet. spp.		2						1
Scutelleridae								
Scutiphora pedicellata							1	
Tingidae								
Teleonemia scrupulosa				1				
Teleonemia sp.							1	
?*Teleonemia* sp.								1
undet. sp.			1					
HYMENOPTERA								
Agaonidae								
undet. sp./spp.		?>1	1				1	
Bethylidae								
undet. sp./spp.	?>1	1	?>1					1
Braconidae								
?*Rogas* sp./spp.								
undet. sp./spp.	?>1	?.1	?>1	?>1	1	?>1	?>1	?>1
Ceraphronidae								
undet. sp./spp.								?>1
Chalcididae								
undet.spp.	?>1	?>2	?>1				1	?>4
Crabronidae								
Bembicinus sp.				1				
Bembix ?kamulla							1	
Bembix sp.				1				
Cerceris ?australis								1
Cerceris minusculis						1		1
Cerceris sp./spp.							1	1
?*Ectemnius* sp.		1						
Spilomena sp.	1							
Encyrtidae								
undet. sp./spp.	?>1	?>1		?>1	1	?>1	?>1	?>1
Eulophidae								
undet. sp./spp.	?>1	?>1	?>1	?>1	1	?>2	?>2	?>2

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Eupelmidae								
undet. sp./spp.				?>1			?>1	
Eurytomidae								
undet. sp./spp.						?>1		
Evaniidae *								
Evania sp./spp.	1		1	>1				
Figitidae								
undet. sp./spp.	?>1	?>1					?>1	?>1
Gasteruptiidae								
Gasteruption ?pallidicus			1					
Gasteruption ?raphidioides				1				
Gasteruption sp. nr. *raphidioides*								1
Gasteruption spp.	1	2					1	
Ichneumonidae								
?*Echthromorpha* sp.								1
Megaspilidae								
undet. sp./spp.								?>1
Mymaridae								
undet. sp./spp.	?>1				1			
Mymarommatidae								
undet. sp./spp.	?>1							
Mutillidae								
Euphutomorpha sp.								1
Pergidae *								
?*Neoeurys* sp./spp.	1		1			1	1	
Perga cincta +			1					
Perilampidae								
undet. sp./spp.							?>1	
Platygastridae								
undet. sp./spp.	?>2	?>2		?>1	?>2	?>2	?>2	?>2
Pompilidae *#								
Calopompilus defensor	1	1						
Calopompilus raptor							1	
Calopompilus spp.	1							3
Heterodontonyx bicolor								1
?*Heterodontonyx* sp.		1						
undet. spp.			3					
Proctotrupidae								
undet. sp./spp.							1	
Pteromalidae								
undet. sp./spp.	?>1	?>1	?>1	?>1	?>1	?>1	?>1	?>1
Scoliidae								
Pseudotrielis zonata							1	
Scolia verticalis							1	
Scolia ?verticalis								1
Scolia sp. nr. *Verticalis*						2		1
Scolia sp./spp.						?>1		1
Sphecidae *#								
Sceliphron laetum								1
Sphex globosus	1							
Sphex ?luctuosus							1	
Thynnidae *#								
Anthobosca australasica		1						
Anthobosca signata							1	
?*Anthobosca* sp.							1	
Agriomyia maculata								1
Agriomyia manifesta						1		
Agriomyia variegata		1						
Dimorphathynnus dimidiatus			1	1				

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
Epactiothynnus ?tasmaniensis			1					
Eirone ?parca								1
Eirone sp. nr. *parca*		1				1	1	1
Eirone schizorhina								1
Hemithynnus apterus				1				
Hemithynnus rufiventris							1	
Lestriocothynnus frauenfeldianus							1	
Rhagigaster sp. nr. *kiandrensis*			1					
Rhagigaster ?mutatus								1
Rhagigaster ?unicolor		1						
Tmesothynnus dispersus								1
Tmesothynnus iridipennis								1
Thynnoturneria sanguinolentus								1
Thynnoturneria sp. nr. *umbripennis*								1
Zeleboria ?contigua			1	1				
Zeleboria xanthorrhoei			1	1				
Torymidae								
undet. sp./spp.	?.1	?>1	1			?>1	?>1	?>1
Vespidae *								
Polistes humilis	1		1					
Ropalidia sp. +							1	
- Eumeninae *								
Abispa splendida #							1	
Abispa ?splendida								1
Bidentodynerus bicolor	1							1
Deuterodiscoellus ephippium #	1							
Elimus australis	1							
?*Epiodynerus* sp.							1	
Paralastor sp./spp.	1		1			1		
?*Paralastor* sp.								1
Pseudabispa confusa #								1
Apiformes								
Apidae *								
Amegilla bombiformis #							1	
Amegilla sp. nr. *bombiformis*							1	
Apis mellifera	1	1	1	1	1	1	1	1
Exoneura spp.	1			2	1	1	3	
?*Exoneura* sp.		1						
Thyreus lugubris							1	
Trigonula carbonaria								1
Xylocopa aeratus #	1	1						
Colletidae *								
- Colletinae								
Leioproctus amabilis		1						
Leioproctus ?amabilis	1							
Leioproctus carinatus	1							
Leioproctus sp. nr. *irroratus*	1							
Leioproctus spp.	1	2				1	3	
Paracolletes sp.		1					1	
- Euryglossinae								
Euryglossa ephippiata	1	1				1	1	1
Euryglossa sp. nr. *occidentalis*		1						
Euryglossa subsericea							1	1
Euryglossa ?subsericea	1	1						
Euryglossa terminata							1	
Euryglossa sp./spp.	2	5				1		2
?*Euryglossella* sp./spp.						1	1	
Pachyprosopis sp./spp.		1				1		1
Sericogaster fasciata						1	1	

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
undet. spp.							1	2
- Hylaeinae								
Amphylaeus ?nubilosellus				1				
Heterapoides sp. nr. *exleyae*	1			1	1			
Heterapoides sp./spp.	2			1				
Hylaeus amiculiformis		1						
Hylaeus sp. nr. *cyanophilus*							1	
Hylaeus elegans		1						1
Hylaeus euxanthus		1						1
Hylaeus sp. nr. *euxanthus*		1						
Hylaeus microphenax				1				
Hylaeus sp. nr. *nubilosus*	1							1
Hylaeus ofarrelli	1							
Hylaeus perhumilis	1							
Hylaeus primulipictus	1	1			1		1	1
Hylaeus ?primulipictus								1
Hylaeus proximus								1
Hylaeus rotundiceps		1						1
Hylaeus turgicollaris								
Hylaeus sp./spp.		2						
Palaeorhiza sp.								1
undet. sp.								1
Halictidae *								
Homalictus brisbanensis	1						1	
Homalictus ?brisbanensis	1	1						1
Homalictus sp. nr. *flindersi*		1						
Homalictus megastigmus				1				
Homalictus punctatus	1							
Homalictus sphecodoides						1		
Homalictus sp.				1				
?Homalictus sp.		1						
Lasioglossum bicingulatum	1	1					1	1
Lasioglossum ?bicingulatum		1					1	
Lasioglossum spp.	1	1			1		3	3
?Lasioglossum spp.	1	?>2					1	
Nomia sp.		1						
Megachilidae *#								
Megachile deanii								1
Megachile lucidiventris							1	1
Megachile maculariformis							1	
Megachile ?mystacea							1	
Megachile ?pictiventris							1	
Megachile punctata						1	1	
?Megachile sp.		1						
undet. sp.		1						
Formicoidea								
Formicidae								
Camponotus sp.	1							
Crematogaster sp.				1				
?Crematogaster sp.		1						
Iridomyrmex spp.		1	1	2	1			4
?Iridomyrmex sp.		1						
Myrmecia nigrocincta	1			1				
Paratrechina sp.						1		
Podomyrma sp. nr. *inermis*	1							
Podomyrma sp.					1			
Rhytidoponera metallica				1				
undet. spp.								2

Taxa	**Sites**							
	1D	1F	2A	2B	2C	3G	4E	4F
LEPIDOPTERA								
Erebidae *								
Amata sp./spp.	1	2	2			1		
?Amata sp./spp.			1					
Asura sp./spp.							1	
Nyctemera amica							1	
Lycaenidae *								
Zizina labradus labradus						1		1
Nymphalidae								
Hypocysta metirius							1	
Papilionidae *#								
Graphium macleayanus	1							
Pieridae *#								
Delias nigrina							1	
Noctuidae								
undet. spp.	2							
?Oecophoridae								
?Snellenia sp.							1	
NEUROPTERA								
Chrysopidae								
undet. sp.	1							
Hemerobiidae								
undet. sp.		1						
Mantispidae								
Spaminta sp.	1							
?Spaminta sp./spp.	1	1						1
undet. sp.		1						
ORTHOPTERA								
Gyrllacrididae								
undet. sp./spp.							1	
PSOCOPTERA								
Caecilidae								
Caecilius ?lineatus				1				
Caecilius spp.	1					1		
Ectopsocidae								
Ectopsocus albiceps				1				
Ectopsocus sp. nr. *briggsi*		1						
Pseudocaeciliidae								
Cladioneura pulchripennis					1			
THYSANOPTERA *								
Aeolothripidae								
Andrewarthaia kellyana		1						
Desmothrips sp./spp.		1				1		
Erythridothrips cubilis	1							
Phlaeothripidae								
Haplothrips ?victoriensis		1						
Haplothrips sp./spp.	1	1	1		1	1	1	1
Thripidae								
Thrips australis	1	1	1					
Thrips ?australis		1						
Thrips hawaiiensis	1							
Thrips imaginis			1					
Thrips setipennis		1	1					
Thrips sp./spp.	1	1			1	1		1

Results and Discussion

Composition of anthophilous insect assemblages can be profoundly influenced by season, variation in rainfall patterns, time of day, daily cycles of temperature and humidity, daylight length, wind, cloudiness, resource availability and foraging behaviour (Barth, 1991, Basset, 1991, Devoto *et al.,* 2009, Norgate *et al*., 2010, Williams & Adam, 2010, Willmer, 2011, Pacini & Dolferus, 2016). The availability and distribution of sun flecks also influences daily activity patterns, and increases in 'sunniness' are known to result in significant increases in insect visitation and consequent fruit set (Gross 1993). The population size of individual insect species that can be sustained within available habitat is likely to be affected by habitat fragmentation and fragment size; which have been widely shown to lead to impoverished faunas, as well as local fauna extinction (Howden & Nealis, 1975, Campbell & Brown, 1994, Aizen & Feinsinger, 1994, Didham, 1997, Laurance & Bierregaard, 1997, Aizen *et al*., 2002, Harris & Johnson, 2004, Huang & Fenster, 2007).

The anthophilous insect assemblages sampled were dominated by Coleoptera, Diptera and Hymenoptera (largely wasps and bees) (Appendix 1). Although numerous taxa >9mm in length were frequently recorded by hand-netting or by visually observing individuals (Table 1), the assemblages, with regard to both species diversity and abundance of individuals, were dominated by insects less than 6mm in length (Williams 1995, Appendix 1). Some of these (e.g., species of Elateridae, Phalacridae, Staphylinidae) were present in large numbers (Williams, 1995, G. Williams unpubl. data). The ubiquitous introduced honey bee *Apis mellifera* was recorded from all species, its presence strongly associated with peak flowering events. Native bees often do not occur in either great diversity or abundance in subtropical rainforest (Williams & Adam, 1997), however, Euryglossinae (Colletidae) were abundant in samples collected on *Syzygium floribundum* and *Tristaniopsis laurina* at Wingham. Colletidae comprise many species (especially Hylaeinae) considered pollen 'thieves' or inefficient pollination agents. Bees of the colletid subfamilies Hylaeinae and Euryglossinae, carry pollen internally in the crop, and may possess specialised brush-like structures on the forelegs with which pollen is swept into the mouth (Michener & Houston, 1991, Exley *et al*., 1993, Houston, 2018); the pollen being harvested for the nutritional benefit of the insects, with few grains incidentally caught on their bodies potentially available for pollination. Buprestidae are well represented, with the speciose and almost endemic Australian genus *Castiarina* known for its co-association (if not co-evolution) with xeric- and mesic-adapted Myrtaceae (Barker, 2006, Bellamy *et. al.,* 2013). The higher incidence of *Castiarina* species (Fig. 2.) recorded from *Syzygium floribundum* in rainforest at Lorien Wildlife Refuge (Table 1) possibly reflects more intensive observation and sampling at that site. However, this diversity was not shared with adjacent co-flowering *Tristaniopsis laurina*; although overlaps in flowering did not occur in each season. Species recorded include a number of predators and parasites (e.g., Eumeninae, Sphecidae, Gasteruptiidae), which as adults also feed on nectar (Naumann *et al.,* 1991, Williams & Adam, 1995). 'Flower wasps' (now Thynnidae, but the species observed were previously placed in Tiphiidae [Johnson *et al.,* 2013]), were at times numerous. Birds were rarely observed, though we do not dismiss their occasional role as pollinators.

Although most anthophilous insects are nectar feeders, a number eat pollen (e.g., certain Chrysomelidae, Coccinellidae, Colletidae, Thysanoptera) but are capable of transporting small pollen loads between flowers (e.g., Appanah & Chan, 1981, House, 1985, 1989, Suetsugu *et al*., 2018). Thysanoptera (e.g., *Thrips setipennis*) are known pollinators of plants in subtropical rainforests (e.g., *Wilkiea huegeliana,* Monimiaceae, *Maclura cochinchinensis*, Moraceae) and in other types of vegetation and on other species (Williams *et. al*., 2001), such that their potential as pollination agents should not be dismissed.

Pollination generalism by suites of small-sized insects is widely recorded among flowering plants (e.g., Bawa, 1994, Waser *et al*., 1996, Sakai *et al*., 1999, Fontaine *et al*., 2009, Maldonado *et al*., 2013, Hasegawa *et al*., 2013, Grant *et al*., 2017, Webb, 2018), and is a strategy considered ancestral in angiosperms (e.g., Shusheng *et al*., 2008). In addition to being on *Syzygium floribundum, Syzygium smithii* and *Tristaniaopsis laurina* small-sized Coleoptera-, Diptera- and Hymenoptera-driven pollen transfer strategies are commonly exhibited by other mass-flowering rainforest trees and shrubs (Williams 1995, Williams & Adam 2010, 2013), in temperate Australia (Ettershank & Ettershank, 1990), and tropical rainforests world-wide (Bawa & Hadley, 1990, Devy & Davidar, 2003, Corlett, 2004). It is a strategy employed by other local lowland rainforest- and wet sclerophyll-associated Myrtaceae (e.g., *Rhodomyrtus psidioides, Rhodamnia rubescens, Backhousia myrtifolia, Syzygium oleosum* [Williams, 2018, G. Williams pers. obs.]), as well as by Myrtaceae in other south-eastern Australian plant communities (Hawkeswood, 1981, 1987, Webb, 1986a, 1986b, 1987, 1989, Griffin *et al*., 2009). However, in our study region, local populations of non-myrtaceous rainforest species (e.g., *Alphitonia excelsa*, Rhamnaceae), whose flowers are otherwise frequented by numerous small insects, may be visited in some years by abundant larger-sized pollinators such as aculeate wasps (Williams & Adam, 1995, 2001, 2010).

General entomophily is exhibited by subtropical *Syzygium floribundum* and *S. smithii* populations, but more ecologically-specialised adaptation to vertebrate and invertebrate pollinators (partly reflected by ramiflorous and cauliflorous positioning of flowers, as in *Syzygium cormiflorum*) is strongly expressed in several Australian tropical species, for example *Syzygium sayeri, S. cormiflorum* and *S. tierneyanum* (Hopper, 1980, Crome & Irvine, 1986, Nic Lughadha & Proença, 1996, Boulter *et al*., 2005). However, general entomophilous pollination strategies are also present in tropical species of *Syzygium*; such as *S. syzygioides* from the lowland rainforests of Sulawesi (Lack & Kevan, 1984), North Queensland's *S. gustavoides* (Kitching *et al*., 2007), and *S. alternifolium, S. heyneanum*, and *S. travanocoricum* from the Western and Eastern Ghats of India (Raju *et al*., 2014, Kuriakose *et al*. 2018).

The populations of individual tree species in mid-north coast NSW lowland rainforests are usually widely dispersed within stands, with a high proportion being obligate out-crossers and existing at low population densities; often few or single trees (Williams, 1995, Williams & Gerrand, 1998a, 1998b, Adam & Williams, 2001). Most flower between October to February (Williams, 1995) and therefore, if present in the same stand, would be competing for pollinators from the same pool of species as that from which the three study species recruit. Species at this latitude are predominantly insect-pollinated, with wind-pollination being a strategy employed by only a few (e.g., *Podocarpus elatus,* Podocarpaceae, *Streblus brunonianus,* Moraceae [Williams & Adam, 1993, 2010]), and vertebrate-adapted species (see Williams & Adam, 2010) being represented solely by *Banksia integrifolia* (Proteaceae) in littoral rainforest remnants (Law, 1993) (and very tall examples associated with elevated hinterland cool temperate rainforest [Adam 1992]). However, the small suite of trees discussed in this paper share a broad spectrum of putative pollinators (Table 1) and this may facilitate ecological resilience and flexibility (e.g., from perturbations of pollinator webs) in achieving pollen transfer and fertilization (Memmott *et al*., 2004, Williams & Adam, 2013, Weismann & Schaefer 2017). Though numerous insects (e.g., some bees and beetles) exhibit resource foraging constancy when flowering events (floral resources) peak, the attendant native anthophilous insect fauna overwhelmingly comprises species with no known fidelity to particular tree or shrub species (Williams, 1995, Williams & Adam, 2010). With the exception of a few bees (e.g., *Amegilla, Xylocopa*) known to exhibit trap-lining foraging patterns (Gross, 1993), individual insects generally are promiscuous in their recruitment habits, being attracted to whatever mass-flowering trees are seasonally in bloom. Consequently co-flowering general entomophilous trees compete for pollinators, with pollen flow between dispersed trees within populations predicted to be non-directional and uncertain. This may have important consequences for the reproductive success and survival of obligate out-breeders and the evolution of floral traits (Renner & Feil, 1993, Bawa, 1994, Minnaar & Anderson, 2019).

The variation in numbers between taxa listed in the checklist (Table 1) in part reflects marked differences in the number and timing of samples and observations undertaken, and the reduced ability to identify species in certain taxa beyond that of order or family (though this did not obstruct recognition of RTUs [given fully in Williams 1995, and in part here in Appendix 1]). However, sampling of mass-flowering canopy trees is unlikely to record the 'total fauna'. 'Rare' species are inherently elusive, and others will be unsampled. We have no sound understanding of the total available pollinator fauna (see discussion in Wardhaugh, 2015). Diptera, in particular, are significantly under-represented in Table 1 (compare with Appendix 1) due to the paucity of available taxonomic expertise with the time required to confront the enormity and taxonomic scope of mass samples produced from studies such as this (e.g., > 20,000 Diptera, approx. 75 percent of which were less than 5 mm in length). In addition, taxonomists rarely concentrate their interests on more than a few families. Consequently, the list is indicative of the wide taxonomic range of species and families that may be encountered, but suggests a rich fauna from which pollinators can be recruited throughout the broader extent of subtropical rainforest found along Australia's eastern seaboard. The list includes numerous larger insects (e.g., various Cetoniinae, Cerambycidae, Papilionidae, aculeate wasps) that undertake frequent and relatively long distance inter-plant movements that may facilitate out-crossing among otherwise self-incompatible Myrtaceae (such as *Syzygium floribundum, Syzygium smithii* and *Tristaniopsis laurina*) (Williams & Adam, 1998, Adam & Williams, 2001). Where species are self-incompatible, the long term survival of single individuals may be tenuous for they are functionally extinct unless populations can be enhanced, or they are agamospermous and able to reproduce by non-sexual means. The limited sampling of a single population of *Syzygium smithii* at the inland Woko site does not allow us to attribute any differences in the insect assemblage between the small-leaved form of that species and the more widespread broad leaved form. However, it is interesting that there are differences.

When our study commenced the advent of the South American pathogen *Austropuccinia psidii* was not anticipated, and its consequent impact on Australian Myrtaceae thus unforeseen; not least the possibility of one of the original Williams 1995 study plants, the related myrtaceous tree *Rhodomyrtus psidioides,* becoming extinct (Makinson, 2018b, Williams, 2018). Anthophilous insects associated with this species are given in Williams (2018).

A native to South America, and possibly Central America, Myrtle rust was first discovered on the New South Wales Central Coast in 2010 and has since spread rapidly reaching far northern Queensland and Melville Island in the Northern Territory by 2015 (Makinson, 2018b). It is now widely established in mesic vegetation communities along the east coast and coastal escarpment, has penetrated onto parts of the tableland in Queensland, and poses a high risk to Australia's natural, social and economic assets. The pathogen has been recorded on a large number of Myrtaceae and is now believed to threaten the survival of numerous susceptible tree and shrub species and genera (e.g., *Angophora, Archirhodomyrtus, Callistemon, Corymbia, Decaspermum, Leptospermum, Melaleuca, Syzygium* and many others) (Simpson *et al*., 2006, Invasive Species Council, 2011, Carnegie *et al*., 2016, NSW Scientific Committee, 2017, Pegg, 2017, Pegg *et al*., 2017, Makinson, 2018a, 2018b). Myrtaceae comprise about 10 percent of Australia's native plant species and the family is an important component of Australia's ecosystems, being structurally and floristically dominant in many (Pegg *et al*., 2017, Makinson 2018b). Makinson (2018b) notes that Myrtle rust has already proved capable of affecting at least 358 native plant species or subspecies (in about 49 genera). He stresses this is only an interim assessment, but illustrates the pathogen's potential to initiate wide scale declines in the extent and abundance of highly susceptible native species, the risk of regional or total extinctions, invasion of currently uninfected areas, the consequent loss of ecological functions within ecosystems, as well as secondary declines of plants and animals closely associated with affected organisms and habitats. As an example of the pathogen's threat level Pegg *et al*. (2017) observed that in wet sclerophyll forest and rainforest sites in south-eastern Queensland there was a massive floristic change with the prior 94 percent dominance of Myrtaceae, in the forest mid-storey being reduced to 63 percent and 37 percent in the 'regeneration' layer.

As a result of the pathogen's wide establishment within Australia, several rainforest-associated trees and shrubs, for example *Rhodomyrtus psidioides* (G. Don) Benth and *Rhodamnia rubescens* (Benth.) Miq. (NSW Scientific Committee, 2017, Pegg *et al*., 2017, Makinson, 2018b, Williams, 2018), are threatened with extinction in nature unless successful recovery strategies can be implemented (Makinson, 2018a, 2018b). Although *Syzygium floribundum, S. smithii* and *Tristaniopsis laurina* in the Manning Valley do not appear to be affected by Myrtle rust, possible extinction events more generally within the Myrtaceae may potentially initiate catastrophic 'landscape-scale' ecological impacts on native plant and animal communities (Pegg *et al*. 2017, Makinson, 2018a).

Many of the larger Coleoptera and Hymenoptera recorded during our study have distributions extending well beyond the New South Wales North Coast, and are known to frequent an array of non-myrtaceous plants growing in open forests, woodland and shrub complexes (Brooks, 1948a, 1948b, 1965, Williams & Williams, 1983, Walton, 1985, Houston, 1992, Cardale, 1993, Braby, 2000, Bellamy *et al*., 2013). This implies a broad pool of putative pollination agents available to the rainforest Myrtaceae flora: but maintenance of the regional generalist pollinator fauna requires the retention of macro- and microhabitats, as well as host resources, for immature insect stages (which are generally poorly known), as well as adult populations. Therefore, should conservation translocations of threatened Myrtaceae be required to avoid Myrtle rust-induced extinction events, as may be the case for *Rhodomyrtus psidioides* (Makinson 2018a), a need to translocate obligate pollinators seems unlikely to arise. Possible obligate host plant-invertebrate herbivore associations and their potential vulnerability to co-extinction (see Moir *et. al*., 2012, Moir, 2013), however, remain to be investigated.

It is possible that more Myrtaceae may be listed as endangered as a result of susceptibility to Myrtle rust, although there is the potential that in some species there may be variation in susceptibility, as has been regionally noted for *Rhodamnia rubescens* (G. Williams pers. obs.), such that under the strong selection pressure imposed by the pathogen less susceptible plants may be selected for so that over time populations may become resistant. However, will the decline or loss of some species have consequences for their associated anthophilous insect community? Reduction in the size of the Myrtaceae population might reduce the resources available for insects, so that the total insect population that can be sustained will be reduced. None of the insect species recorded from the three Myrtaceae species discussed in this paper have obligate associations with flowering plants, so loss of resources, while affecting population size, is unlikely to be directly responsible for reducing the conservation status of individual insect species.

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Appendix 1. Selected examples of numbers of individual insects and taxa (as morphospecies/RTUs) from mass-collected samples (after Williams, 1995). Key:'Ind./spp.' = number of individuals/ number of insect species (RTUs). Date of sample cited. 'T' = tree. Month of collection follows day. Where cited 'm' = sample collected in morning (between 9-11am), 'a' sample collected in afternoon (between 1-3pm)

Syzygium floribundum **LorienWildlife Refuge**	Ind./spp. T1. m. 29.11.1991	Ind./spp. T1. a. 29.11.1991	Ind./spp. T1. m. 5.12.1991	Ind./spp. T1. a. 5.12.1991		
total Coleoptera	288/23	104/15	118/15	153/17		
total Diptera	153/30	149/19	106/17	95/26		
total all Hymenoptera	69/46	55/42	12/9	30/21		
s/total bees	31/19	26/13	1/1	11/6		
total visitors	529/108	325/82	240/44	284/70		
total individuals <6mm	524	314	227	275		
total individuals >9mm	5	5	1	1		
Syzygium floribundum **LorienWildlife Refuge continued.**	Ind./spp. T2. m. 29.11.1991	Ind./spp. T2. a. 29.11.1991	Ind./spp. T2. m. 5.12.1991	Ind./spp. T2. a. 5.12.1991		
total Coleoptera	161/20	58/14	482/27	186/31		
total Diptera	477/24	235/18	139/26	103/17		
total all Hymenoptera	48/35	41/25	31/19	31/23		
s/total bees	27/17	21/12	13/7	20/14		
total visitors	705/88	345/62	675/83	327/75		
total individuals <6mm	691	326	665	314		
total individuals >9mm	4	1	5	5		
Syzygium floribundum **Wingham Brush Nature Reserve**	Ind./spp. T2. m. 19.11.1991	Ind./spp. T2. a. 19.11.1991	Ind./spp. T2. m. 27.11.1991	Ind./spp. T2. a. 27.11.1991	Ind./spp. T2. m. 3.12.1991	Ind./spp. T2. a. 3.12.1991
total Coleoptera	11/7	40/14	44/16	39/19	27/16	83/29
total Diptera	166/14	366/26	257/21	766/39	428/26	508/25
total all Hymenoptera	15/11	23/15	31/12	107/34	45/19	83/29
s/total bees	9/6	11/7	11/5	14/7	18/6	21/9
total visitors	202/36	449/63	343/53	980/105	542/72	707/92
total individuals <6mm	189	415	313	949	517	657
total individuals >9mm	3	4	6	10	12	28
Syzygium floribundum **Wingham Brush Nature Reserve continued.**	Ind./spp. T2. m. 10.12.1991	Ind./spp. T2. a. 10.12.1991	Ind./spp. T2. m. 17.12.1991	Ind./spp. T2. a. 17.12.1991		
total Coleoptera	27/14	70/32	54/22	28/16		
total Diptera	627/24	406/25	253/26	274/25		
total all Hymenoptera	75/22	73/28	57/22	58/26		
s/total bees	53/12	14/8	31/9	20/10		
total visitors	755/63	569/97	380/81	365/72		
total individuals <6mm	737	530	331	342		
total individuals >9mm	8	13	28	10		
***Syzygium smithii* -** **Lansdowne Nature Reserve.**	Ind./spp. T1. 6.11.1990	Ind./spp. T1. 12.11.1990	Ind./spp. T1. 15.11.1990			
total Coleoptera	157/35	308/51	155/26			
total Diptera	265/18	273/19	87/19			
total all Hymenoptera	21/17	29/17	9/9			
s/total bees	4/4	5/4	2/2			
total visitors	491/84	696/107	261/54			
total individuals <6mm	471	656	234			
total individuals >9mm	3	2	2			

***Syzygium smithii* - Manning Point.**	Ind./spp. T1. 3.11.1990	Ind./spp. T1. 8.11.1990	Ind./spp. T1. 15.11.1990	Ind./spp. T2. 8.11.1990	Ind./spp. T2. 15.11.1990	
total Coleoptera	25/13	107/17	34/7	79/28	1199/12	
total Diptera	43/12	64/15	35/11	86/16	95/23	
total all Hymenoptera	16/11	15/6	25/4	18/8	8/8	
s/total bees	10/5	10/1	1/1	11/5	0/0	
total visitors	98/41	193/41	99/27	188/55	1318/51	
total individuals <6mm	83	184	96	177	1318	
total individuals >9mm	0	7	1	8	2	
***Syzygium smithii* –Woko National Park.**	Ind./spp. T1. m. 25.11.1990	Ind./spp. T1. a. 25.11.1990	Ind./spp. T1. m. 5.12.1990	Ind./spp. T2. m. 25.11.1990	Ind./spp. T2. a. 25.11.1990	Ind./spp. T3. m. 5.12.1990
total Coleoptera	83/26	131/34	214/32	61/35	34/19	1425/56
total Diptera	130/17	60/19	51/16	38/14	25/16	139/23
total all Hymenoptera	7/6	31/16	22/12	21/11	33/21	29/14
s/total bees	0/0	6/6	1/1	0/0	2/2	2/1
total visitors	341/57	309/81	338/73	157/71	180/72	1663/104
total individuals <6mm	242	258	320	145	167	1464
total individuals >9mm	11	38	7	4	5	15
***Tristaniopsis laurina* – Lorien Wildlife Refuge.**	Ind./spp. T1. m. 26.12.1991	Ind./spp. T1. a. 26.12.1991	Ind./spp. T1. m. 3.1.1992	Ind./spp. T1. a. 3.1.1992	Ind./spp. T1. m. 6.1.1992	Ind./spp. T1.a. 6.1.1992
total Coleoptera	24/16	10/9	40/9	35/12	42/13	18/10
total Diptera	107/21	28/7	80/29	49/14	311/26	163/20
total all Hymenoptera	32/28	19/15	18/13	45/34	33/25	33/23
s/total bees	11/10	11/7	3/3	27/18	5/1	5/4
total visitors	197/69	57/31	140/52	133/64	402/71	221/59
total individuals <6mm	180	45	131	108	394	215
total individuals >9mm	12	6	4	12	6	2
***Tristaniopsis laurina* – Wingham Brush Nature Reserve continued.**	Ind./spp. T3. m. 2.1.1992	Ind./spp. T3. a. 2.1.1992	Ind./spp. T3. m. 2.1.1992	Ind./spp. T3. a. 2.1.1992	Ind./spp. T4. m. 7.1.1992	Ind./spp. T4. a. 7.1.1992
total Coleoptera	62/17	99/14	85/15	90/17	390/16	194/9
total Diptera	168/18	319/19	283/20	120/24	169/20	121/20
total all Hymenoptera	31/17	102/35	45/25	43/14	26/12	38/15
s/total bees	11/5	22/13	14/5	7/5	6/3	6/3
total visitors	274/59	531/72	421/66	260/59	592/52	358/52
total individuals <6mm	253	487	399	236	585	353
total individuals >9mm	0	7	10	9	2	2

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A valuable early record of Norfolk Island plants: the 1790s watercolours of convict artist John Doody and accompanying notes by William Paterson

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Abstract: An album of 50 watercolour illustrations depicting Norfolk Island plants attributed to convict artist John Doody, in the early 1790s, and associated notes apparently written by William Paterson (1755-1810), one-time commander of the military detachment on Norfolk Island, Lieutenant Governor of New South Wales, and amateur botanist, are described and assessed. Illustrated are 48 plant species growing on Norfolk Island at the time, all but three of which are indigenous. The notes and the watercolours represent the only treatment of the island's flora in the 18th century and include descriptive and ecological material for the species at the time of first European occupation. Two of the species are now extinct. Paterson's notes also include an introductory description of the flora and fauna of the Island. The importance of this material to the modern study of the Norfolk Island flora is highlighted.

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Introduction

Early European accounts of plants found in recently settled localities often provide valuable information for the modern-day botanist researching the botany of that place. These accounts are almost always made by non-botanists and generally provide few details. Usually, formal names are not available for the taxa, although detailed descriptions and/or paintings can be used today to accurately identify the species involved.

There are few detailed accounts of the flora of Norfolk Island from the 18th and 19th Centuries. Early government officials and the comments made by casual visitors gave much attention to the Norfolk Island Pine *Araucaria heterophylla* and the Flax *Phormium tenax*. These two plants, whose possible commercial potential as masts and cordage respectively, was enthusiastically promoted by James Cook upon his discovery of Norfolk Island in October 1774, are frequently mentioned in the early literature. The presence of these species to a large degree prompted the settlement of Norfolk Island by the British in March 1788, but in the end, neither species was to meet the potential importance to the British Navy originally envisaged.

From 1788, when Norfolk Island was first settled as a convict prison until 1900, there were very infrequent visits by botanists and competent naturalists. The majority of the plants only became known to science following the first published *Flora* prepared by the Austrian botanist Stephano Endlicher in his *Prodromus* of 1833. This work was based on the collections of botanical artist Ferdinand Bauer who visited the island in 1804-05; Endlicher never visiting the island. 'Government botanist' Allan Cunningham spent several months on the island in 1830 (Mills 2012), providing a most valuable description of the flora, three years before the work of Endlicher. Quaker missionary and naturalist James Backhouse visited in 1835 and, having the advantage of Endlicher's *Prodromus*, provided competent commentary on the plants he observed (Backhouse 1843). The next major treatment of the flora was by Joseph Maiden (1904), who compiled an annotated list of the plants for the island after a visit in 1902. Ten years later, New Zealander Robert Laing produced an updated list of plants following his visit to the island in 1912 (Laing 1914). The current *Flora* was published in the *Flora of Australia* series and was prepared largely by Kew botanist Peter Green (Green 1994). Recent work has documented changes in the understanding of the indigenous flora and made many additions to the list of naturalised species (e.g. de Lange *et al*. 2005; Mills 2010a).

Pre-1800 descriptions of the plants occurring on Norfolk Island are particularly rare. Accounts by James Cook and his shipmates, Philip Gidley King, first commandant on Norfolk Island, and a few other naval and military officers provide brief descriptions only. Their accounts invariably mention the thick rainforest growing on the island, the rich soils and some of the more peculiar plants, at least to English eyes. This is not to say that such accounts are not valuable. The only person to prepare an account with any sort of comprehensive treatment of the plants in those early years of settlement was William Paterson (1755-1810), who was in charge of the military detachment on Norfolk Island from November 1791 to March 1793. This paper discusses the Norfolk Island botanical notes attributed to William Paterson and the associated watercolours attributed to his servant, convict artist John Doody.

The historical material

The Paterson/Doody material is contained in an album of watercolours (call no. DL PXX 1), held by the Mitchell Library, part of the State Library of New South Wales, Sydney. The album contains sheets depicting watercolours of the plants growing on Norfolk Island in 1792; the additional sheets are due to some species having more than one sheet attached to the number. Additionally, inserted into the album are 11 pages of handwritten notes. These notes are obviously associated with the watercolours, as the species numbering on the sheets corresponds to that in the notes.

In addition to the watercolours attributable to John Doody, there are three sheets showing the Norfolk Island endemic species *Freycinetia baueriana*. Based on style and quality, these are unlikely to have been produced by Doody. On the back of the painting of the fruit is written 'Capt King Nov. 21, 1794', referring to Philip Gidley King, who was commandant on Norfolk Island for two periods between 1788 to 1796. While the three paintings are associated with King, there is no evidence that he was the artist. There are also four sheets in the album showing plants that do not occur on Norfolk Island; these species grow around Sydney, New South Wales and are clearly by a different artist. Based on known works, these paintings appear to be by George Raper, well known First Fleet artist, or are copies of his artwork; one painting matches a Raper painting depicted in the book by Groom (2009). These sheets require separate assessment.

There are several documents at the Mitchell Library associated with the above album; these are:

i) a typed list and some notes in a folder, loosely held in the album;

ii) an album of black and white photographs of the watercolours;

iii) various notes on the watercolours in a separate folder (call no. PXn 196);

iv) a scanned copy of the album available on the State Library of NSW online site;

v) online State Library notes compiled by SLNSW staff.

The album was bequeathed to the SLNSW in 1952 by William Dixson, Sydney businessman and major benefactor of the State Library of NSW, as part of his very large private collection of Australian historical material. There is apparently no earlier confirmed information on the provenance of the Paterson/Doody material. As discussed below, it is thought that the notes and paintings were originally sent by William Paterson to Joseph Banks in England around 1794.

William Paterson (1755-1810) and John Doody (fl. 1790s)

The watercolours have been attributed to convict John Doody, based on a letter from William Paterson to Joseph Banks on 12 December 1794. Paterson at the time was Lieutenant Governor and acting administrator in Sydney, a position he held from December 1794 to September 1795 prior to the arrival of John Hunter as Governor of the Colony. In a postscript to the letter of 12 December, Paterson writes "The drawings are done by a young man who came out in *Barrington* with me, a Convict, he has been my servant ever since & is known I believe to Mr Latham, to whom he has wrote, to any person collecting he might be made very useful; his name is Jno. Doody."

Although not a terribly competent botanist, Paterson was a keen natural historian and artist and in regular correspondence with the influential botanist and President of the Royal Society, Joseph Banks in London. He had been sending Banks various natural history objects, writings and paintings for many years; Paterson's book on his African exploits was dedicated to Banks (Paterson 1790). Paterson's aim was to obtain the support of Banks for his admission as a fellow to the Royal Society. In his letter to Joseph Banks of 12th December 1794, Paterson writes "In a letter to Gov^r King you are so good to offer me your assistance in publishing the natural history of Norfolk Island, but my sudden return from that place put it out of my power to finish what I intended viz. the Birds and Fishes. However, with the drawings &c that accompany's this you will be in possession of the Botanical part, and from the few specimens of the strata which were sent before, you will be able to judge of the formation of the island. Should you think the memorandums worth publishing or if it could be done by offering them to the Royal Society I would consider the Honor still greater, at the same time may I beg to solicit your interest of becoming a Fellow of the Society & hope by my attention to Natural History you will think me deserving of that honor."

In a letter to Paterson on 1st March 1797, Banks replied "I note your wishes to become a Fellow of the Royal Society but during your residence abroad I believe it to be impossible when you return your chance of receiving that & the Literary honors must depend upon the benefit science has receivd from your Labors while abroad and as the elections into that body are carried on by Ballot I shall have no doubt of your success provided the Members are convinced that you deserve their white balls." A white ball was a yes vote from members for admission as a fellow of the Society, while a black ball was a vote against admission. Paterson's ambition to become a Fellow was not achieved until he returned to England on sick leave in 1798. He eventually returned to Port Jackson to become Lieutenant Governor from 1800 to 1808 including four years as Commandant of Van Diemens Land (Tasmania). He died off Cape Horn on 21 June 1810 on his way to England.

John Doody was sentenced to seven years transportation as a convict on 10th December 1788. He arrived in the fledgling colony of Sydney on the *Admiral Barrington*, part of the Third Fleet, on 16th October 1791. He soon became the servant of William Paterson and arrived with him on Norfolk Island on 4th November 1791. Doody left the island with Paterson some 16 months later, on 9th March 1793. Two years later, Paterson, then administrator at Sydney, granted Doody, by then a free man, 30 acres of waterfront land up river from Sydney. The location was originally called Doody's Bay and later became known as Gladesville, after John Glade, a later owner of the land. No other information on John Doody could be located. The fern genus *Doodia*, of which there are two species recorded for Norfolk Island, is named after English botanist Samuel Doody (1656-1706); there is no connection to the convict John Doody.

Paterson's Descriptive Notes of the Flora and Fauna of Norfolk Island

The individual plant notes are preceded by several paragraphs containing descriptions of some of the plants and animals of Norfolk Island; a verbatim transcription of the notes appears below, in italics. These notes are reproduced exactly as Paterson wrote them; punctuation, spelling and grammar are all faithfully reproduced as in the original manuscript. For better understanding of the notes, the currently accepted names of the plant and animal species being referred to are inserted within square brackets.

Though the soil and Climate of Norfolk Island are very favourable for most plants, notwithstanding this vegetation has many enemies to encounter, first the Grub very destructive to the roots of most plants & often get into the cobbs of the India Corn which they seldom leave till the whole is destroyd it is to be hoped that the discovery of lime on this Island will in some degree put a stop to their doing so much mischief. Second a great variety of Caterpillars distroy almost every Garden vegetable, particularly at this Season when we have no rain The Easterly winds are also very bad where the land is not sheltered but the worst of all is a small Insect which I have calld the Locust of Norfolk Island, this year they made their appearance early in November I observed on the skirts of the woods where the Ground had been cleared (between Sydney Bay & Queensburgh) and planted with India Corn which promised to be a very fine crop the Insects were very little larger than a Gnat with small tufts of a white downy hair they adhered to a species creeper very common in the woods & in such numbers that they compleatly coverd the leaves & twigs of the plant when I touched the branch they sprung all about me they are a species of Grilla and I believe the smallest of that tribe - Early in December they made their appearance on the leaves and stalks of the India Corn they have now four transparrent wings & the whole Insect including the wings was little larger than ¼ of an Inch from tip to tip, their powers of suction are so strong that in a few days the whole juice of the plant is nearly extracted and hangs upon the leaves a sweet glutonus substance which partly puts a stop to Vegetation and prevents the Cobb being properly formed.

This plant [Freycinetia baueriana] is chiefly found in the woods in most parts of the Island when growing clear of trees it is seldom higher than thirteen feet but when among Trees it climbs as high as fifty feet or upwards & the leaves are nearly as strong as that of the Ananas [the pineapple genus] & from three to four feet long growing in a spiral manner in three rows up the stem and terminates in a large Crown within which is enclosed the flower The Calyx (if it may be so called) is composed of six leaves much broader than the rest tinged of a flesh colour towards the bottom and a dark green towards the top, they intersect the spines within them are six flesh colourd Petals placed in right angles. The spathas are five in number though I have found them often with three & four irregularly placed and inserted in five of the Petals they are about six inches in length & coverd to the top with a very thin dark buff colourd Farina the leaves of the flower are so very fleshy that they cannot be dryd the speciman and drawing will I hope be sufficient to describe the plant. Most of the arboreas plants of this Island produce either a rosinous or gummy substance. The Pine Tree [Araucaria heterophylla] produces vast quantitys of a thick rosin which they here call Turpentine and hitherto has not been used to any purpose except an ingrediant in Soap it is rather singular that the wood does not in the least partake of the rosin the whole is in the bark and in the knotts This is the largest Tree in the Island and grows in great numbers some of them has been found 250 feet high and a beautifull wood of a much closer grain than our fir it is chiefly used for building the knots of this Tree appears not to be the least perishable for those that have been blown down and the whole trunk mouldered to dust you find the knots quite fresh and almost transparrent from the quantity of rosin they contain and burn as clear as a Candle - The other trees have as yet been little used what they have named the yellow wood the black wood and the mahogany appear to be excellent for Cabinet work. There is a species of the Hibiscus [Lagunaria patersonia] that grows to a large Tree which I think is a new plant it produces a quantity of Gum in appearance and quality to that of the Gum Arabic, the flower is a light red and the leaves a very light green and downy -

The Blood Tree [Baloghia inophylla] is remarkable when wounded a watery substance issues from it very much like blood experiment has hitherto been made but I think it might be usefull in Varnish or Staining wood & perhaps in dyes. The foliage of all the plants and the Flowers are elegant there are two species of Solanum that will be a great acquisition to our Green houses in England the one bears beautifull clusters of most delicate snow white flowers and continues in flower and fruit most of the year [Solanum bauerianum] the fruit is a small dark red berry hanging in large clusters and adds much to the elegance of the plant it grows to about six feet the other has very large dark green jaged leaves and bears a large purple flower in clusters the fruit about the size of a plum [Solanum laciniatum] oval and a deep Orange colour - there is also a species of Vaccinium [a genus of shrubs in the plant Family Ericaceae] a beautifull shrub and bears a deep Orange colourd berry [probably Alyxia gynopogon] - the Convolvulus's are many and elegant. Passiflora [Passiflora aurantia] also a very beautifull Jasminum [Jasminum simplicifolium] two species of Piper the one with a large cordated leaf the fruit of an Orange colour when ripe and very pleasant to the taste [Macropiper excelsum subsp. psittacorum], the other is a very minute plant with small oval succulent leaves and in general found growing upon the trunks of decayd trees [Peperomia urvilleana], I have also discoverd a new species of Morus [Streblus pendulinus].

The Cryptogamias are both numerous and beautifull particularly of the ferns. The fern tree [Cyathea brownii] is elegant & usefull it is excellent food for the stock particularly Hogs and many of the Inhabitants eat it when there is necessity of reducing their allowance of provissions (which has often been the case) The Cabbage Palm [Rhopalostylis baueri] is also found to be a very usefull plant but from the quantity of Ground cleared & the many People constantly cutting it for use in a short time it will become very scarce but it is to be hoped Garden Vegetables will sufficiently supply its place it grows from thirty to forty feet has a naked stem with a large Crown of leaves at the top in appearance much like the Coco Nut tree –

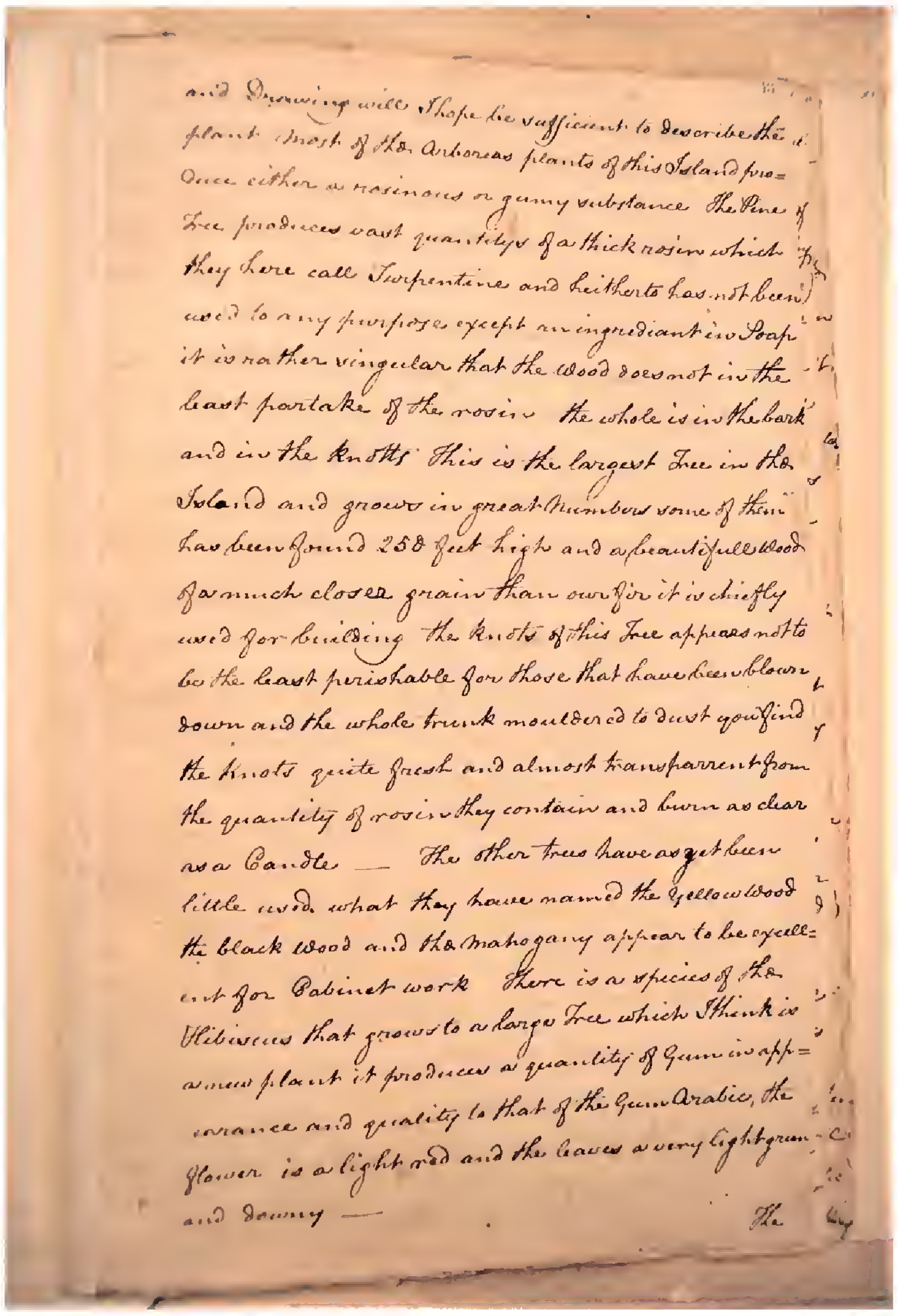
Quadrupeds

There has only one kind been found upon the Island the Rat [Rattus exulans] which differs only in size from our Common Rat in being much smaller -

Birds

The birds peculiar to the Island & usefull are 1st the Pigeon are in vast numbers a beautifull plumage & much larger that the English wood Pigeon [Wood Pigeon Hemiphaga novaeseelandiae sadicea] very good to eat & easily killd. 2nd a large Parrot [Norfolk Island Kaka Nestor productus] with brown red & dirty coloured yellow plumage also good to eat there are also some beautifull Doves [Norfolk Island Ground Dove Gallicolumba norfolciensis] but seldom got a species of Carlew [? Whimbrel Numenius phaeopus] - Parroquites green with a red head [Green Parrot Cyanoramphus cookii] -

The Mount Pitt bird (species of the Petrill) [Providence Petrel Pterodroma solandri] is the most usefull the season of their coming to this Island is in March and it is supposed they come from New Caledonia but that is merely conjecture, they however come in vast numbers Mount Pitt is the principal part of the Island to which they resort and the soil being of a deep light Earth is more adapted for their making their holes in the day time they go to Sea and return regularly when it becomes dark on the Island when the People are generally waiting their arrival they catch them by means of a torch which is made of the pine Knots the birds come down to the light and are immediately siezed and put into a bag, some Thousands have been taken in one Night If it was not for these birds at this small allowance of Provission many of the Convicts must Die for want Those that are not able to go into the woods receive a Certain proportion from the others.



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it is rather singular that the Wood does not in the
least partake of the rosin the whole is in the bark
and in the knotts This is the largest Tree in the
Island and grows in great Numbers some of them
has been found 250 feet high and a beautifull Wood
of a much closer grain than our fir it is chiefly
used for building the knots of this Tree appears not to
be the least perishable for those that have been blown
down and the whole trunk mouldered to dust you find
the knots quite fresh and almost transparrent from
the quantity of rosin they contain and burn as clear
as a Candle — The other trees have as yet been
little used what they have named the Yellow Wood
the black Wood and the Mahogany appear to be excell=
ent for Cabinet work There is a species of the
Hibiscus that grows to a large Tree which I think is
a new plant it produces a quantity of Gum in app=
earance and quality to that of the Gum Arabic, the
flower is a light red and the leaves a very light green
and downy —
The

Fig. 1. Page 3 of William Paterson's notes. Mitchell Library, call no. DL PXX 1.

Doody's Norfolk Island watercolours and Paterson's individual plant notes

The main set of watercolour illustrations in the album is numbered from 1 to 50 and depict 48 plant species; two species are illustrated twice and separately numbered. The watercolours are painted on large drawing paper about 47 cm by 60 cm. Some sheets exhibit paintings of more than one plant species, while several illustrate different parts of the plant, such as cross-sections of flowers or fruit. The watercolours have apparently been numbered at the time of their production but are not signed or dated. Various plant names appear on the sheets, but very few are given a binomial name, as no names were available at the time for most of the plants depicted. On many of the sheets, there are pencil notes, often of a single genus name. These were almost certainly added later by someone with botanical knowledge, but before 1833 when most of the species were formally described and named. Some of these pencil notes are followed by a stylised letter 'B', possibly indicating the botanist who made the note.

Notes held at the Mitchell Library in Sydney (call no. PXn 196), state that Owen Evans, a Norfolk Islander with an intimate knowledge of the island's natural history, visited the Library in 1970 and identified the species illustrated. The list of species identifications is contained with the notes; the species are correctly identified although some of the names used in the list have since been superseded.

Among the documents listed above, several different numbering systems are used for the watercolours. The original numbering system, from 1 to 50, corresponds to the notes by Paterson and is the numbering system used here. Number one in the series is the only one out of sequence in the album; these three sheets appear at the end of the album rather than the beginning.

Each of the plants illustrated are discussed below, under the sheet number, with current taxon name, family and current common name, priority being given to the local Norfolk Island name. The plant notes made by William Paterson pertaining to each of the Doody watercolours are in italics; these are brief descriptions and/or names given to the plants depicted and provide interesting contemporary descriptive and ecological information. Additional comments are provided by the author. Scanned copies of the watercolours are available online at http://archival.sl.nsw.gov.au/ Details/ archive/110371293.

No. 1 (3 illustrations) *Freycinetia baueriana* Endl. (Pandanaceae) Mountain Rush

No 1 Two of the Male & Female plants the stem of which is about three inches in circumferance and of an equal thickness to the top it Climbs up the Trees from 80 to 100 feet high & throws out roots at every joint when it is clear of woods it seldom grows above 13 feet high - The leaves grow in a spiral manner on the stem about three or four feet long and terminates with the flower on the top as represented the numbers of Male or Female on one plant are very irregular sometimes six and in some only three - The fleshy leaves of the flower are very pleasant to the taste the fruit is very Gluttonous and I believe very nourishing but having no pleasant flavor is but little used except by the Convicts who go in the woods in search of birds - This plant grows in vast quantitys about Mount Pitt. Flowers in Nov^{r} and the Fruit is ripe in May

One drawing is numbered '1', although the next two in the album are clearly part of a set of three. This Norfolk Island endemic produces the spectacular flower heads depicted in the painting; see Figure 2. The pencil note 'Pandanus inclinans?' refers to the New Zealand species now known as *Freycinetia banksii*. The watercolour shows flowering and fruiting spikes, and cross-sections of flowering parts, as well as the large red bracts of the inflorescence and the plant's leaves.

No. 2 *Myoporum obscurum* Endl. (Scrophulariaceae) Popwood

No 2 Grows to about 30ft high the flower is white with purple spots in the inside the berry is of a deep purple with one stone the leaves are a very dark green & shining

This small tree is endemic to the island; wild plants are very rare today, although it is being planted around the island. The main painting illustrates a stem with flowers and fruits, and there are smaller sketches of a flower, the developing fruit and a cross section of a mature fruit.

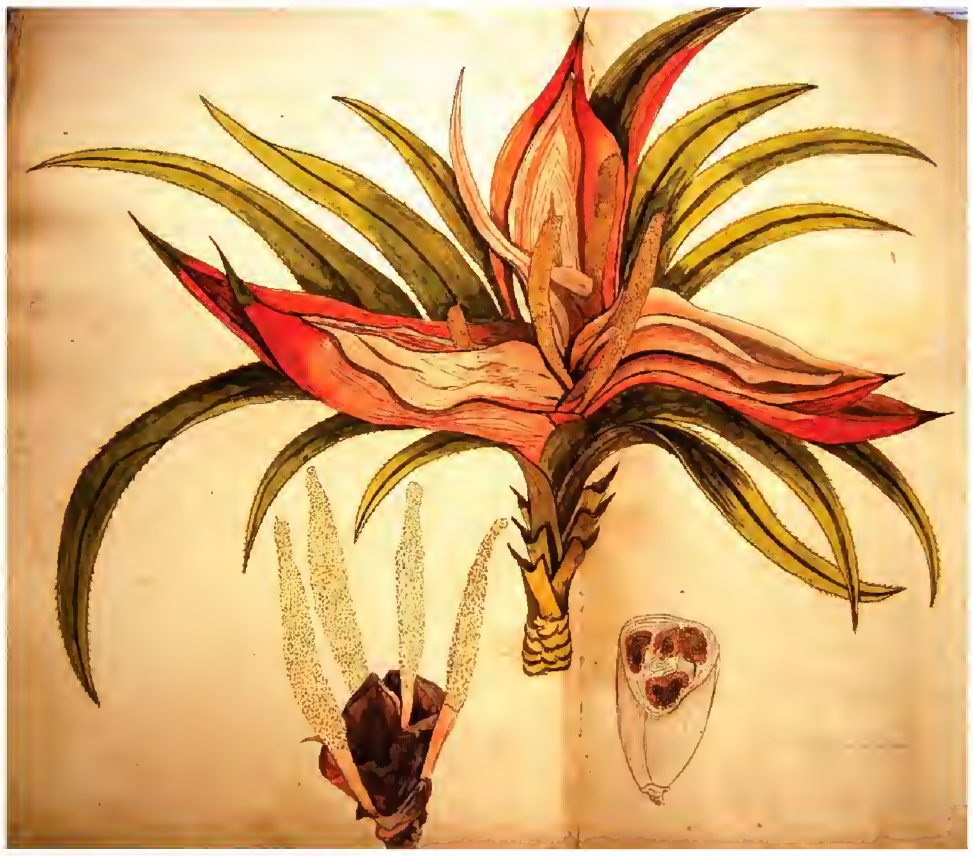

Fig. 2. No.1 Inflorescence of *Freycinetia baueriana* (Pandanaceae), an endemic monocot.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 3 *Celtis paniculata* (Endl.) Planch. (Cannabaceae)
Whitewood

No 3 Grows to a Tree it is rather scarce on the Island the wood of it has not as yet been used I have not been able to find any more perfect than what is represented in the Drawing

This relatively common tree on Norfolk Island, particularly at lower altitudes, also occurs in eastern Australia and New Caledonia. 'Celtis' is written in pencil on the lower part of the sheet. The watercolour shows a stem and leaves, with panicles of small fruits, which are blackish when ripe, and a small cross-section of a fruit. This same species is also illustrated in painting No. 19. The type specimen of this widely occurring tree comes from Norfolk Island.

No. 4 (2 illustrations) *Coprosma baueri* Endl. (Rubiaceae) Coastal Coprosma

No 4 Male & Female plants It grows only where exposed to the Sea & seldom above 12 feet high the Fruit is good to eat

This endemic shrub is rare on Norfolk Island, and is now mostly found on nearby Phillip Island where it is relatively common. There are scattered plants around the Norfolk Island coast and it is in cultivation there. The paintings, both labelled 'No. 4', show stems and leaves, as well as male and female plants, the latter showing the orange-coloured fruit of the species. The pencil note appears to be 'Erythroxylum'; *Erythroxylum* (family Erythroxylaceae) is the Coca genus of South America.

No. 5 *Cordyline obtecta* (Graham) Baker (Asparagaceae)
Ti

No 5 A Species of Aletris [a genus in the lily family, Liliaceae] grows in swampy ground is about 30 feet high when in flower has a most beautifull appearance & pleasant smell

This species, also occurring in New Zealand, is related to other species of *Cordyline* found through much of the southern hemisphere and India. 'Dracaena terminalis', written on the sheet in pencil, is a synonym of *Cordyline fruticosa*, a species indigenous to tropical areas from Asia through northern Australia and extending to some Polynesian islands. The watercolour shows the large leaves and flowering head in bud and what appears to be an individual flower in the top right-hand corner of the sheet. The species was described in 1827 from a plant cultivated at the Royal Botanic Gardens Edinburgh (Green 1994).

No. 6 *Meryta angustifolia* (Endl.) Seem. (Araliaceae)
Narrow-leaved Meryta

No 6 Grows to about 15 feet high the leaves are a strong arromatic the wood very soft & brittle Goats are remarkably fond of this plant

This is one of two species of *Meryta* on Norfolk Island, both of which are endemic. This painting depicts the narrow-leaved species, which is today common in the forests in the national park. The watercolour shows a stem with leaves and the female inflorescence, with smaller sketches of a flower and the fruit. There is also a separate drawing of part of a male panicle. The words 'Genus Euphorbia?' are in pencil. The wider-leaved species, *Meryta latifolia*, is not illustrated. Both species were first described by Endlicher (1833) under the genus name *Botryodendrum*.

No. 7 (2 illustrations) *Wikstroemia australis* Endl. (Thymelaeaceae) Kurrajong

No 7 This plant grows sometimes to about 20 feet the leaves are beautifull the flower very minute bearing a small berry with a single seed the drawing of both are Magnifyed. The bark is very tough and usefull in tieing up Torches etc but soon rots when put in water they have given it the name of the Cotton plant

One painting shows the immature leaves of the plant, which are much broader and longer than the leaves found on mature trees, and a raceme of flowers. The second shows a stem with mature leaves and fruit along with small sketches of a flower and a seed; see Figure 3. The distinctive reticulation of the veins on the leaves is illustrated on both watercolours. Also drawn are cross-sections of the tubular flower and a seed. This rare, endemic small tree has been reduced greatly in abundance over the past 30 years (Mills 2010b).

No. 8 *Ipomoea alba* L. (Convolvulaceae)
Moon Flower

No 8 A very large white Convolvulus the stalks are very usefull for feeding swine

The large white flower and climbing habit leave little doubt as to the specific identity of this plant. This is not an indigenous Norfolk Island species; it is listed by Green (1994) as introduced to the island. The painting shows the typical twining growth habit, tendrils and the characteristic flowers of *Ipomoea*. Also illustrated are smaller sketches of a bud, a flower and a style.

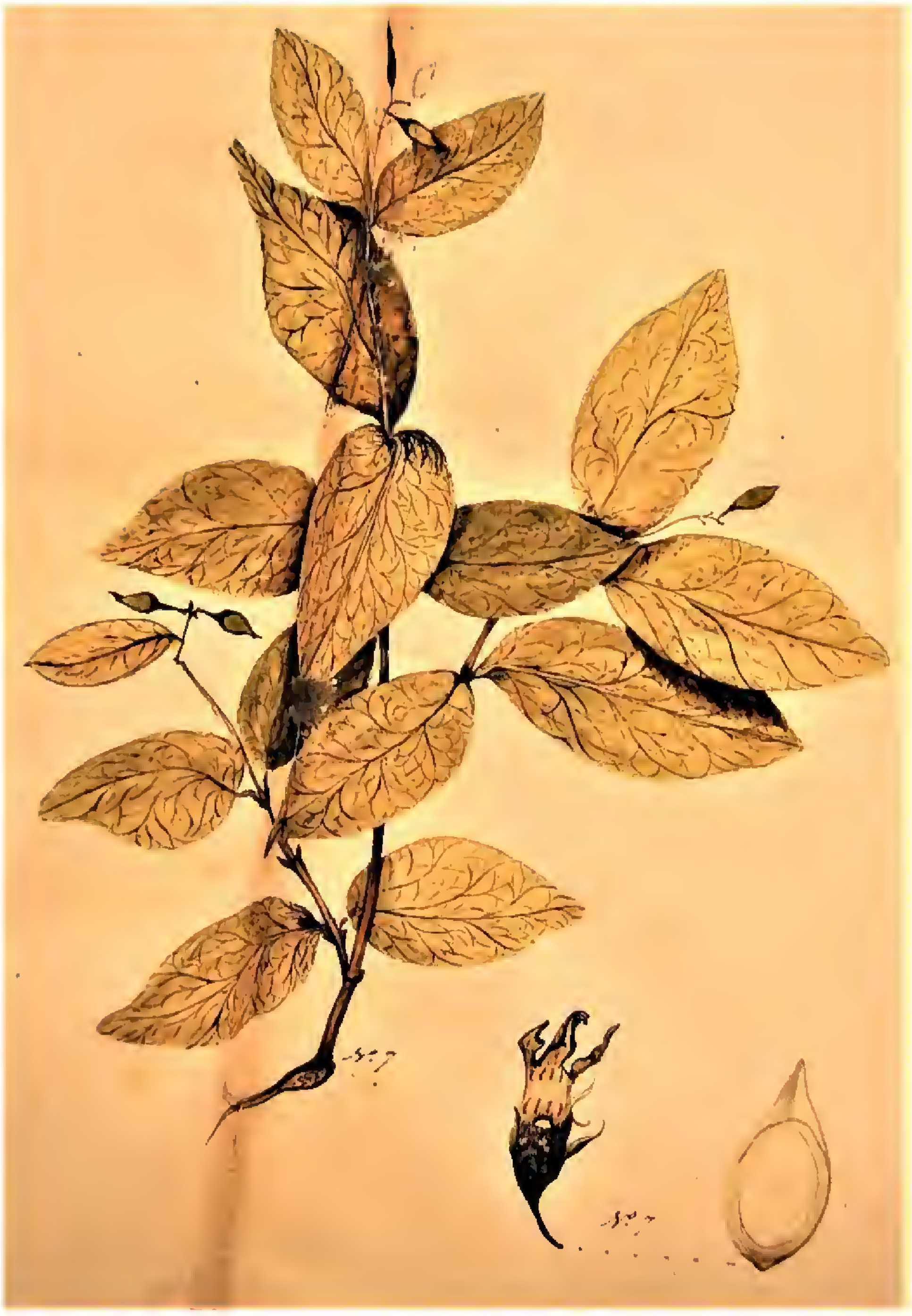

Fig. 3. No.7 *Wikstroemia australis* (Thymelaeaceae), an endemic tree.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 9 *Calystegia affinis* Endl. (Convolvulaceae)
Bindweed

No 9 Convolvulus Flower & leaf natural size

This rather rare species on Norfolk Island is endemic to that island and Lord Howe Island; following further study, it may be described as a Norfolk Island endemic. *'Convolvulus'*, a genus in the same family, is written in pencil on the sheet. The watercolour shows the characteristic twining stem, sagittate leaves and flowers, which in this case shown pinkish rather than the usual white.

No. 10 *Pennantia endlicheri* Reissek (Pennantiaceae)
Pennantia

No 10 Grows to a small Tree the leaves of a beautifull light green flowers white & very minute & has a very pleasant smell.

This tree is endemic to Norfolk Island and is moderately common in the rainforest in the national park. The painting shows the large leaves with their prominent veins and an inflorescence with flowers and buds; there are also two small sketches of flowers. This species was named by Siegfried Reissek in 1842 after Austrian Stephano Endlicher who prepared the first flora for Norfolk Island in 1833, and who had included it in his *Prodromus* under the name *Pennantia corymbosa*, a New Zealand species.

No. 11 *Dendrobium macropus* (Endl.) Rchb.f. ex Lindl. subsp. *macropus* (Orchidaceae) Long-caned Orchid
(syn. *Thelychiton macropus* Endl)

No 11 Natural size found chiefly on rocks or decayd Trees

This rather common epiphytic orchid grows on trees and rocks throughout the island; the subspecies is endemic to Norfolk Island. The watercolour illustrates the whole plant, including the yellowish flowers. There are also two small sketches of a flower and detail of the interior of a flower. There is a pencilled name on the sheet that may be 'Epidendrum', another large genus in the family Orchidaceae. This subspecies was recognised in 1986 when the Lord Howe Island plants were described as a separate subspecies.

No. 12 *Plumbago zeylanica* L. (Plumbaginaceae)
Native Plumbago

No 12 Natural size found only at Duncomb Bay the same is very common in the East Indias flowers in October

This is a widespread shrub, ranging from Africa through Asia, Australia and the Pacific islands. This watercolour shows a stem with leaves and the white flowers, with two smaller illustrations of flower parts. A pencil note 'Plumbago zeylanica' correctly identifies the species. Paterson writes "found only at Duncomb Bay", where the species is still found today.

No. 13 *Elatostema montanum* Endl. (Urticaceae)
Mountain Procris

No 13 Found in different parts of the Island but in abundance about Mount Pitt the stem very succulant and the flower when magnified appears like small pieces of Sea weed stuck on I think there are Male & Female of this plant and that the Drawing is the male the leaves are very irregular as there are some three two & one from the stalk but in general only one Flowers in Nov^{r}

This endemic species, known also as *Procris montana*, was placed in the genus *Elatostema* by Endlicher in 1833 to where it has been returned. This is a very rare species of mountain gullies and moist rocky outcrops in the national park. The watercolour illustrates a stem and the largish leaves along with the almost sessile inflorescences.

No. 14 *Solanum bauerianum* Endl. (Solanaceae)
Bridal Flower

14 A most beautifull white Solanum flowers in Oct^{r} & continues in flower and fruit untill June it bears a small red berry in clusters

This is clearly one of the three species of *Solanum* recognised as once occurring on Norfolk Island. Two species have quite different leaves to this species, which are never lobed. The species illustrated is *Solanum bauerianum*, now extinct but originally found on Norfolk and Lord Howe Islands. The painting shows a stem with leaves and the white flowers. A painting of this species has been reproduced in colour using the sketch and colour information prepared by Ferdinand Bauer who visited the island in 1804-05 (Mabberley *et al*. 2007).

No. 15 *Solanum laciniatum* Aiton (Solanaceae)
Large-flowered Kangaroo Apple

15 Purple flowering Solanum Continues in flower & fruit for about nine months.

This second species of *Solanum* is *S. laciniatum*; now extinct on Norfolk Island it still occurs in Australia and New Zealand. 'Solanum laciniatum' is written in pencil below the drawing. de Lange *et al*. (2005) identify this painting as this species rather than the closely related *S. aviculare*, which also once occurred on Norfolk Island. The watercolour shows a stem with the large lobed leaves and the blueish flowers, developing fruit and a bright red mature fruit, the latter typical of this species. This drawing is the only record of this species having occurred on Norfolk Island.

No. 16 *Melicope littoralis* (Endl.) T.G.Hartley (Rutaceae)
Shade Tree

16 Grows to a small Tree the whole a very fine Arromatic and produces a Yellow Gum, flowers in October

This tree was previously described as *Euodia littoralis* by Endlicher (1833). The painting shows a stem with the three leaflets typical of this genus and two inflorescences with small white flowers. Smaller sketches show flowers, a fruit and cross-sections of two seeds. The species name is a misnomer, as the species grows in the inland mountain rainforest rather than on the coast.

No. 17 *Pisonia brunoniana* Endl. (Nyctaginaceae)
Wai-wai, Birdcatcher

*17 Grows about 12 feet high the wood is very soft flowers in Oct^r^*

Pisonia brunoniana occurs from New Zealand to Hawaii and is closely related to other species of *Pisonia* growing in Australia and elsewhere; the type specimen comes from Norfolk Island. The watercolour depicts the large leaves and flowering inflorescence, with smaller sketches of flower parts and the characteristic narrow fruit; see Figure 4.

No. 18 *Calystegia soldanella* (L.) Roem.& Schult. (Convolvulaceae) Beach Calystegia

18 Convolvulus found on the Sea side flowers in October

The widespread beach plant *Calystegia soldanella* is now very rare or even extinct on the island. The watercolour illustrates the creeping habit and pinkish flowers of the species. 'Convolvulus' is written in pencil; this species was previously known as *Convolvulus soldanella*.

No. 19 *Celtis paniculata* (Endl.) Planch. (Cannabaceae)
Whitewood

19 Grows to a Tree the flower so minute as not to be described

This is the second watercolour of this tree in the series; the other is Drawing No. 3. The two illustrations are similar and show the stems, leaves, small flowers and developing fruit; No. 3 is the better painting.

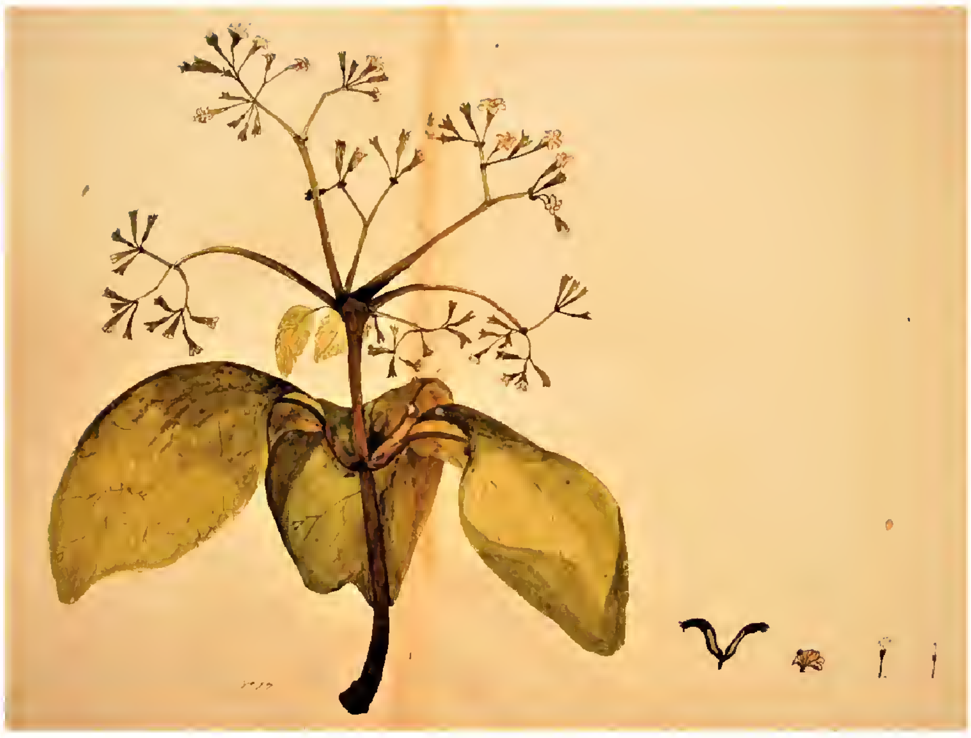

Fig. 4. No. 17 *Pisonia brunoniana* Endl. (Nyctaginaceae). Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 20 (2 illustrations) *Melodinus baueri* Endl. (Apocynaceae) Big Creeper

20 This plant is found chiefly in the woods it climbs up the trees and some times from one tree to another for some hundreds of feet the fruit is ripe in about April & tasts something like the mespilas the plants are often twisted together like Ships Cables

There are two illustrations of this robust endemic vine, one showing a stem with the inflorescence and smaller sketches of flowers, the other showing the typical large fruit of the plant. There is also a sketch of a cross-section of a fruit, showing the flesh and seeds contained within. 'Melodinus ?' and 'Genus apocin ?' are written in pencil, the latter referring to the family name. This species is also illustrated in watercolour No. 48.

No. 21 *Lagunaria patersonia* (Andrews) G.Don (Malvaceae) White Oak

21 Hibiscus Grows to a very large Tree flowers in November the wood is usefull in boat building and produces a Gum I think nearly equal to that of the Gum Arabic.

This is a very common tree on Norfolk Island, growing as stunted sea cliff shrubs to very large forest trees. The species also grows on Lord Howe Island. The painting shows a stem with leaves and the pinkish flowers, including smaller detailed illustrations of the petals and other flower parts. 'Hibiscus' is written in pencil, a genus in the same family. This species was named *Hibiscus patersonia* in 1803 by Henry Andrews after William Paterson.

No. 22 *Alyxia gynopogon* Roem. & Schult. (Apocynaceae)
Evergreen

22 Grows to about 10 feet high

This endemic shrub was originally named in 1786 as *Gynopogon alyxia* by Georg Forster, who visited the island with James Cook in 1774. *Alyxia* is a common shrub of the rainforest in the national park on Norfolk Island. The watercolour illustrates a stem with the four-whorled leaves, white flowers and bright orange/red fruit characteristic of this species; see Figure 5. A pencil note says 'Alyxia'.

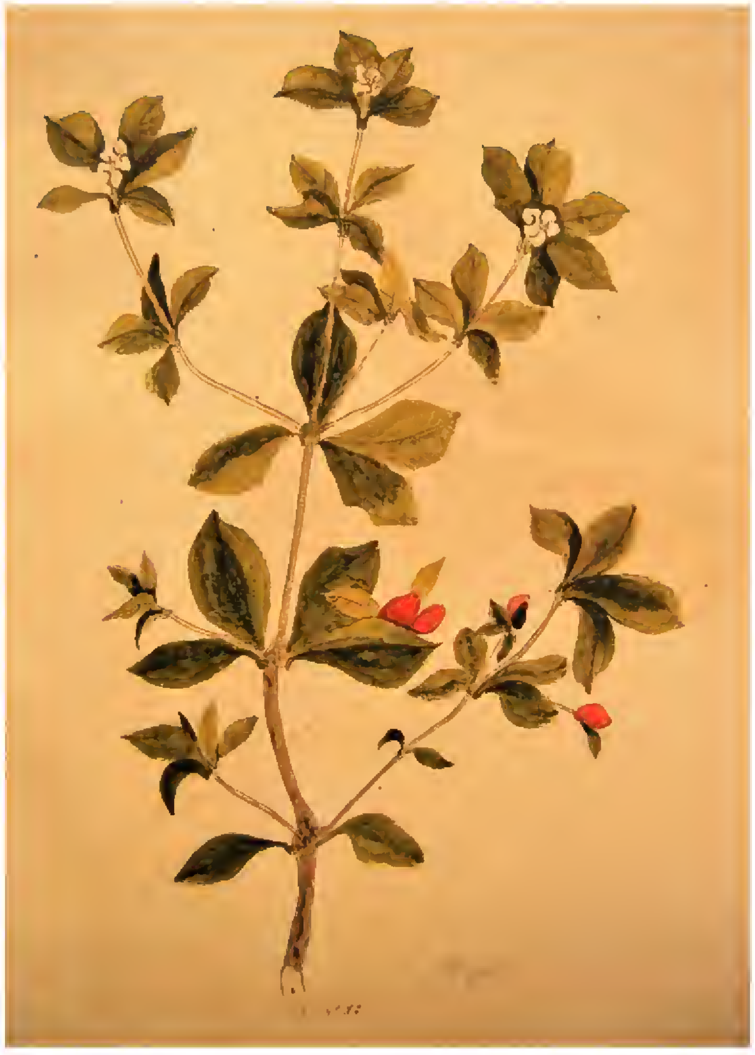

Fig. 5. No.22 *Alyxia gynopogon* (Apocynaceae), a Norfolk Island endemic shrub.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 23 *Melicytus latifolius* (Endl.) P.S.Green (Violaceae) Norfolk Island Mahoe

23 (Pentandria monogynia) grows to a tree the flowers very minute and of a light green colour

This endemic tree is quite rare and very scattered across the national park and occasionally elsewhere on the island. The species was originally placed in the genus *Hymenanthera* by Endlicher (1833). The painting depicts a stem with leaves and the small fruit of the species, which are borne along the stems. Three flowers are shown in smaller sketches. The pencil note 'Pentandria' alludes to an old category of plants; Paterson's notes refer to 'Pentandria monogynia'. The broader and somewhat darker leaves of this species, along with the lack of small marginal teeth, can be compared with *Melicytus ramiflorus* subsp. *oblongifolius* in drawing No. 43.

No. 24 *Streblus pendulinus* (Endl.) F.Muell. (Moraceae) Siah's Backbone

24 Grows to about 20 feet high the leaves are very rough and answer the purpose of polishing wood the same as fish skin

This endemic tree is uncommon in the rainforest of the national park and occasionally elsewhere on the island. This name was until recently applied to plants from a wide area of the southwest Pacific east to Hawaii; the name now applies to the Norfolk Island taxon only (Conn 2015). The watercolour shows a stem with leaves and the distinctive long, narrow flowering catkins of the male inflorescence and the small female flower spike. 'Caturus' in pencil is a synonym of *Acalypha*, in the family Euphorbiaceae; the pendulous male inflorescences of *Streblus* resemble those of some species in that genus.

No. 25 *Boehmeria australis* Endl. subsp. *australis* (Urticaceae) Nettletree

*25 Grows near Water & about 12 feet high flowers in Nov^r^*

This is a rare tree belonging to the stinging nettle family. This Norfolk Island endemic subspecies is recognised in Australia, with subspecies *dealbata* occurring on the Kermadec Islands. These subspecies are not recognised in New Zealand, to which the Kermadec Islands belong, and where a different generic designation is recognised, *Pouzolzia australis*. The painting shows the rather large, thin, serrated leaves of the species and the clustered axillary flowers.

No. 26 *Geitonoplesium cymosum* (R.Br.) A.Cunn. ex R.Br. (Hemerocallidaceae) Scrambling Lily

*26 Flower & fruit natural size it is generally found climbing up the trees flowers in Nov^r^*

This species is moderately common in some places in the rainforest on Norfolk Island; it is a common creeper in eastern Australia. The drawing shows the twining stem with leaves, the whitish flowers and the dark-coloured fruit, and there is a small drawing of a flower. The wide leaves of the Norfolk Island plants, illustrated in the painting, are considerably broader than those of the Australian plant. The pencil note reference to 'Convallarioides' is uncertain; it may refer to a supposed similarity to the genus *Convallaria*.

No. 27 *Tetragonia implexicoma* (Miq.) Hook.f. (Aizoaceae) Native Spinach

27 A Creeper found generally near the sea

This prostrate herb is moderately common around the edges of Norfolk Island, where it grows on sea cliffs and sand dunes in semi-shaded situations below pines. The species also occurs in southern Australia and New Zealand. The leaves and creeping stem, along with the yellow flowers and the bright red fruit of this plant are illustrated (see Figure 6), and readily distinguish it from the green-fruited *T. tetragonoides*, which also occurs on the island.

No. 28 *Capparis nobilis* (Endl.) F.Muell ex Benth. (Capparaceae) Devil's Guts

28 found climbing up trees the fruit is eatable

This robust endemic climbing vine is common in the forest and often climbs into the tops of tall trees. The leaves, large white flowers and the large purple fruit are distinctive and illustrated in the watercolour, although the stout, recurved spines present along the branches are not shown. A small drawing shows a cross-section of a fruit. 'Capparis' in pencil at the bottom of the sheet correctly identifies the genus. The species was named and described by Endlicher (1833) as *Busbeckia nobilis*.

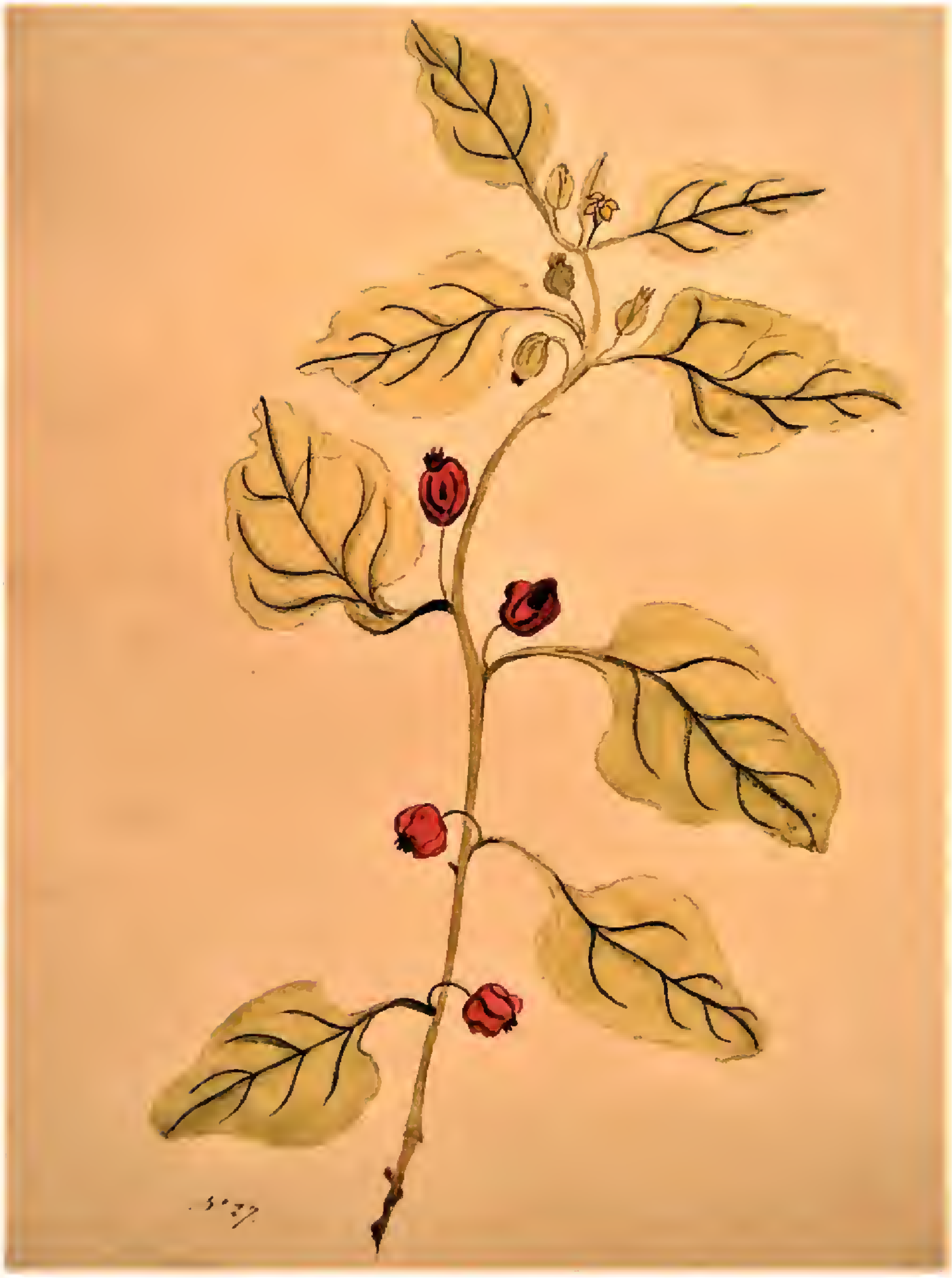

Fig. 6. No. 27 *Tetragonia implexicoma* (Aizoaceae)
Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 29 *Samolus repens* (J.R.Forst. & G.Forst.) Pers. (Primulaceae) Creeping Brookweed

29 Found growing on the rocks on the Sea shore the drawing is natural size the flowers are sometimes white

This small coastal plant is widespread, from Australia to New Zealand and New Caledonia. The watercolour illustrates a stem with leaves and the small pinkish flowers of the species, with a smaller drawing of a flower. Small colonies are quite common in moist places near the sea around Norfolk Island.

No. 30 *Baloghia inophylla* (G.Forst.) P.S.Green (Euphorbiaceae) Bloodwood

30 The Blood Tree grows very straight from 50 to 60 ft high when the bark is cut a liquid issues out something like blood and in vast quantitys, it has been used here for painting furniture but does not answer the purpose as the least wet brings it off when it is properly prepared there is little doubt but that it may become very usefull the Colour when put on is that of a very dark mahogany the wood splits easily & is used chiefly for paleing

This plant was originally described as *Croton inophyllus* by Georg Forster, based on material collected in New Caledonia in 1774 during Cook's second voyage to the Pacific. It has also been known as *Baloghia lucida*. This tree is common in subtropical rainforest on the east coast of Australia. The watercolour shows a stem with the large leaves, small white flowers and the distinctive fruit of the species, while small sketches show a flower and a cross-section of a mature fruit.

No. 31 (2 illustrations) *Phormium tenax* J.R.Forst. & G.Forst. (Hemerocallidaceae) Flax

31 Two drawings of the flax plant one from a scale of 9 ft the other natural size flowers in October.

This common coastal plant on Norfolk Island occurs in New Zealand and some of its surrounding islands. Despite some reservations about it being indigenous (Coyne 2011), there is no convincing evidence suggesting Polynesian introduction (Mills 2011). The watercolours, on separate pages and both numbered 31, depict the whole plant, the folded leaf, the tall inflorescence, flowers and fruit. A pencil note gives the correct species name, which was collected in New Zealand by the Forsters in 1774 and described by them in 1776.

No. 32 *Nestegis apetala* (Vahl.) L.A.S.Johnson (Oleaceae) Ironwood

*32 Grows to a tree the fruit when ripe tastes something like raisins the wood is very hard but has not as yet been used for any purpose - fruit is ripe in Dec^r^*

This tree, related to the edible olive and previously named *Olea apetala*, is very common in the rainforest on the island. The species also occurs in New Zealand, from where the type specimen was collected. The watercolour shows a fruiting stem with leaves, along with a small drawing of a cross-section of a fruit.

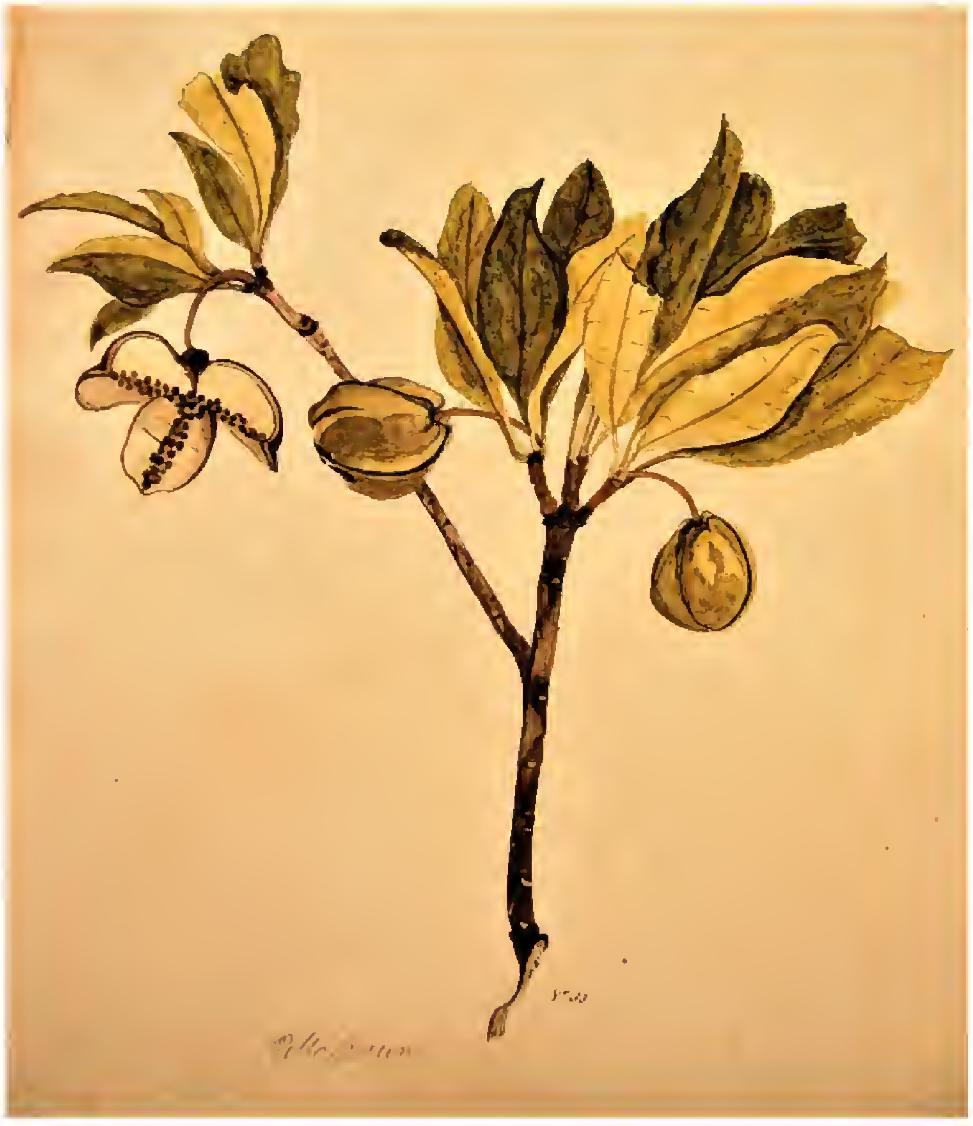

Fig. 7. No.33. *Pittosporum bracteolatum* (Pittosporaceae), a tree endemic to Norfolk Island.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 33 *Pittosporum bracteolatum* Endl. (Pittosporaceae) Oleander

33 Grows to a Tree and produces on oily substance when the fruit opens the seeds appear as if rubbd with oil & of a jet black

This endemic tree is very common in the rainforest on the island. The watercolour shows a stem with leaves and the fruit of the species, one showing the distinctive split fruit; see Figure 7. A pencil note 'Pittosporum' correctly identifies the genus.

No. 34 *Jasminum simplicifolium* G.Forst. subsp. *australiense* P.S.Green (Oleaceae) Jasmine

34 Jasminum

This shrubby creeper is common in the rainforest and may be a low shrub or a slender high-climbing creeper. The painting shows the creeping stem with leaves, several inflorescences with the fragrant white flowers and the black fruit. A pencil note 'Jasminum lucidum' refers to an earlier name. The species is also known from eastern Australia and Lord Howe Island.

No. 35 *Peperomia urvilleana* A.Rich. (Piperaceae) Two-leaved Peperomia

35 A species of Piper found growing on rocks & decayed trees the leaves succulant the fruit very minute.

This small herbaceous epiphyte grows on rocks and trees in the rainforest. The watercolour shows a stem with leaves and two narrow flowering spikes covered in tiny black seeds. A pencil note *Piper* is a genus in the same family. The species is widespread in the southwest Pacific, including New Zealand where the type material was collected.

No. 36 *Passiflora aurantia* G.Forst. (Passifloraceae) Norfolk Island Passionfruit

36 Passiflora

The species is rather uncommon on the island, usually growing in light gaps and on the edges of the forest. The watercolour depicts the climbing stem with leaves, characteristic tendrils of *Passiflora* and the large, attractive red flowers. A pencil note 'Passiflora' denotes the genus.

No. 37 *Ipomoea indica* (Burm.) Merr. (Convolvulaceae) Blue Morning Glory

37 Convolvulus found about Cascade Bay

This species was previously known as *Ipomoea congesta*; it is not indigenous to Norfolk Island. The plant was obviously introduced soon after European settlement in 1788. The painting shows the climbing stem and the large flowers, which appear pinkish, but the colour has probably faded from the original blue colour of this species. Pencil notes 'Convolvulus?' and 'Ipomoea?' refer to two genera in the family Convolvulaceae.

No. 38 *Elaeodendron curtipendulum* Endl. (Celastraceae) Maple

38 Grows to a large Tree

This tree is quite common on the island, often growing on dry ridges. The watercolour shows a stem and leaves, along with the distinctive dentate leaves, some small flowers, immature fruit and the blue-black mature fruit, along with a small sketch of a cross-section of a fruit; see Figure 8. Pencil notes are 'Genus Rhamnos', referring to the family Rhamnaceae, and 'Drupe seed (?) cerussatus'; another note is difficult to decipher. 'Cerussatus' meaning 'white lead' refers to the colour of the fruit, which are covered in a whitish bloom. The type specimen comes from Norfolk Island, although the species is not endemic to the island.

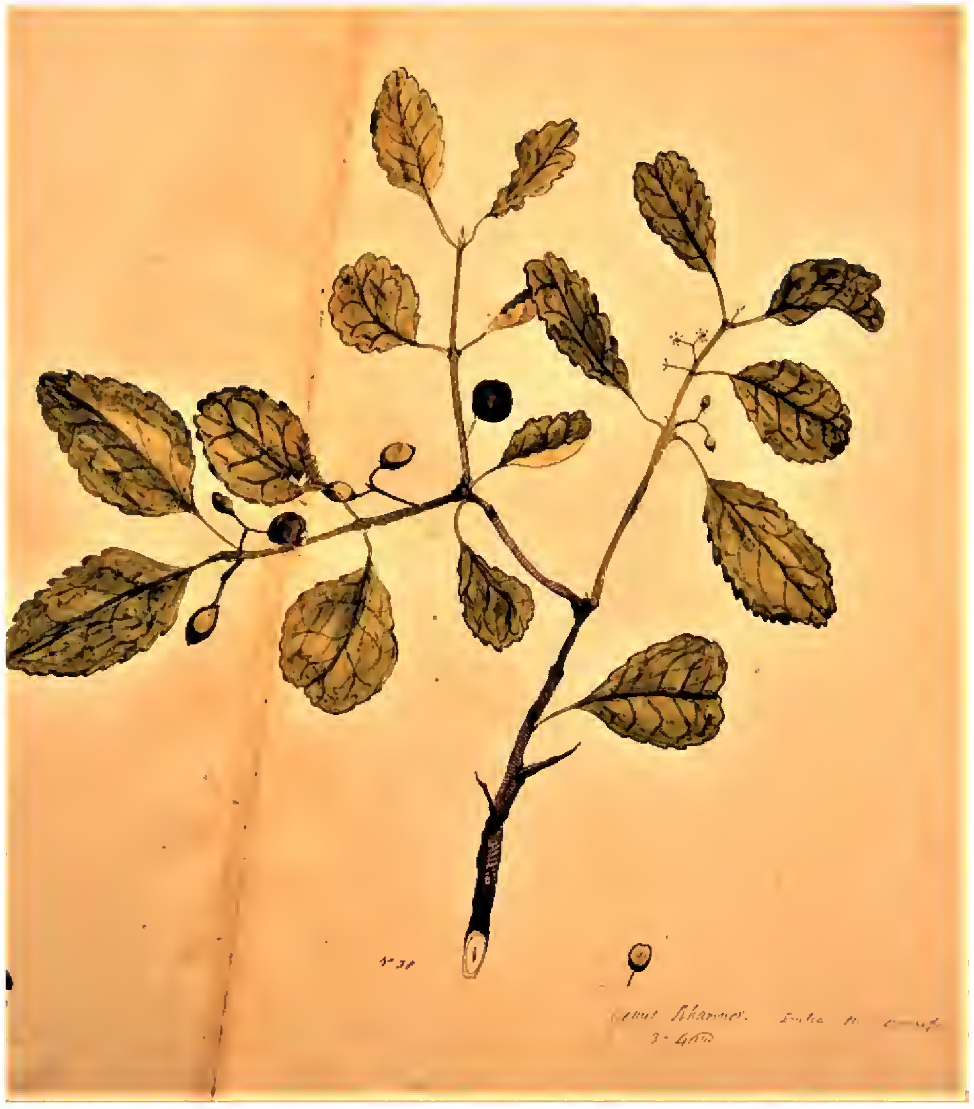

Fig. 8. No. 38 *Elaeodendron curtipendulum* (Celastraceae). Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 39 *Euphorbia obliqua* Endl. (Euphorbiaceae) Spurge

39 Euphorbia natural size found in Sandy Ground near the Sea

On Norfolk Island, this species mostly grows on the calcarenite rock along the south-western part of the island and on Nepean Island. The watercolour shows the whole plant, including roots, as well as the small flowers and fruit. This small herbaceous species is also found on the tropical islands to the north, New Caledonia and Vanuatu.

No. 40 *Lobelia anceps* L.f. (Campanulaceae)
Lobelia

40 Natural size

This herbaceous plant is quite common on the coast in some places, particularly along the southern edge of Norfolk Island. Illustrated is a leafy branch, the small purplish flowers and a fruit, with smaller sketches of flower parts. A pencil note reads 'Lobelia cf [compare with] L. angulatam'. *Lobelia angulata* is a closely related New Zealand plant. *L. anceps* is widespread in the southern hemisphere and was previously known as *Lobelia alata.*

No. 41 *Ipomoea cairica* (L.) Sweet (Convolvulaceae)
Coast Morning Glory

41 Convolvulus flowers in October

This species may or may not be indigenous to Norfolk Island; it is now ubiquitous throughout the Pacific and it is unclear to which regions it was originally native. Depicted are the twining habit of the plant, the distinctive palmate leaves and the large pinkish flowers. A pencil note reads 'Ipomoea'. The suggestion by Lange *et al.* (2005) that this species is indigenous because of the early date of this painting cannot be substantiated (Mills 2010c). The species is treated as a serious weed on Norfolk.

No. 42 *Planchonella costata* (Endl.) Pierre (Sapotaceae)
Bastard Ironwood

*42 Grows to a large tree, the Pigeons are very fond of the fruit which is ripe in Nov^r^*

This endemic tree is uncommon in the rainforest and found mostly at low altitudes. Originally named *Achras costata* by Endlicher (1833), it has since been known by several names, and has been placed in the genus *Pouteria* more than once. The painting shows a stem with leaves, the flowers in bud and the orange fruit of this species, with smaller sketches of flower parts and the characteristic large seed.

No. 43 *Melicytus ramiflorus* J.R.Forst. & G.Forst. subsp. *oblongifolius* (A.Cunn. ex Heward) P.S.Green (Violaceae)
Whiteywood

Yellow wood

This taxon is common in the rainforest in the national park, being far more abundant than *M. latifolia*, illustrated in watercolour No. 23. The painting shows a stem with leaves, the small fruit that are produced along the branches of this plant, hence the specific name. The pencil note reads 'Yellow Tree' and below the word Tree 'Wood' is written later by a second hand. Presumably the pencil note 'Ignot', appearing to be written by the second hand, means unknown (L. *ignotus*). Other species on the island in the family Rutaceae are today called Yellow Wood.

No. 44 *Ungeria floribunda* Schott & Endl. (Malvaceae)
Bastard Oak

44 Grows to a large Tree & has a beautifull appearance when in flower

This is an interesting monotypic genus that is endemic to Norfolk Island. The large brown, ribbed fruit are illustrated, as are the large leaves and an inflorescence of red flowers; see Figure 9. Smaller sketches show flowers and a cross-section of a fruit. The pencil note 'Helicteres' refers to another genus in the family Malvaceae; a stylised 'B' is written beside the name.

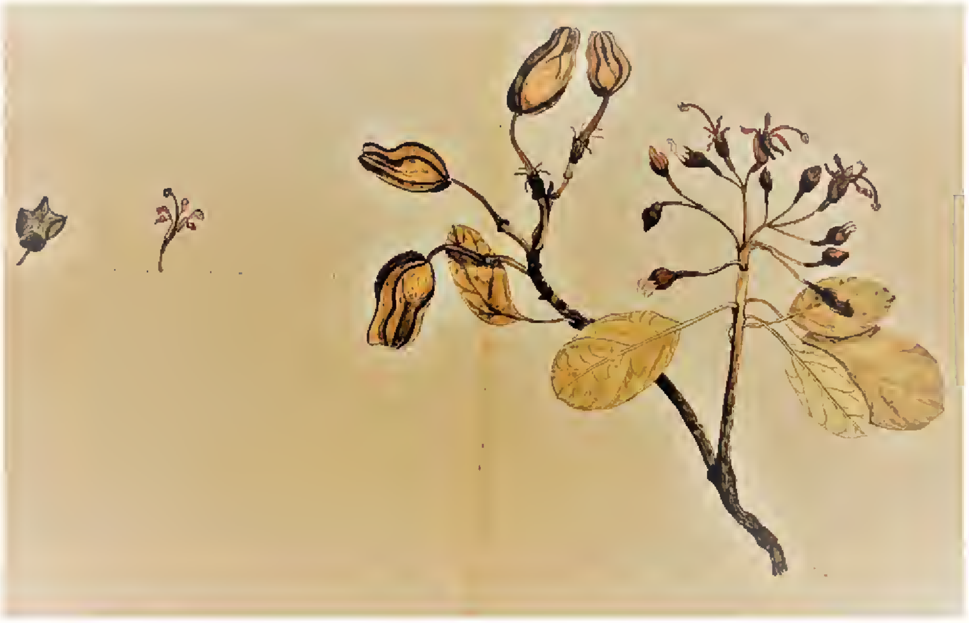

Fig. 9. No.44 *Ungeria floribunda* (Malvaceae), a genus endemic to Norfolk Island.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney DLP XX 1.)

No. 45 (2 illustrations) *Dianella intermedia* Endl. (Hemerocallidaceae) Dianella

*45 Natural size found growing among the flax plants Hexandria monogynia flowers in Nov^r^*

This endemic plant is now rather common in the national park, where it has been extensively planted along the walking tracks. Illustrated are two plants, one with an inflorescence of white flowers, the other showing the blue fruit; the first also shows a small sketch of a flower. A pencil note reads 'Dianella caerulea', a common eastern Australian species. This taxon is regarded as endemic by de Lange and Murray (2003), thus separating it from the as yet un-named Lord Howe Island plant.

No. 46 *Abutilon julianae* Endl. (Malvaceae)
Norfolk Island Abutilon

46 Grows to about 8 feet high found near the Far Bay as there are only a few plants here and in no other part of the Island I am doubtfull wether they have not been brought by some of the first Settlers

This species was thought extinct until a few years ago when it was found on Phillip Island, following the removal of Rabbits from that island. The species originally also grew on Norfolk Island, where it is now quite commonly planted. The watercolour depicts the large serrated leaves, the yellowish flowers and typical dry fruit of *Abutilon*; see Figure 10. Smaller sketches of flower parts are also shown. A pencil note reads ‘Sida’, a genus in the same family as *Abutilon*, below that is ‘cf asiaticum’. The plant being referred to is the African species now known as *Abutilon asiaticum*.

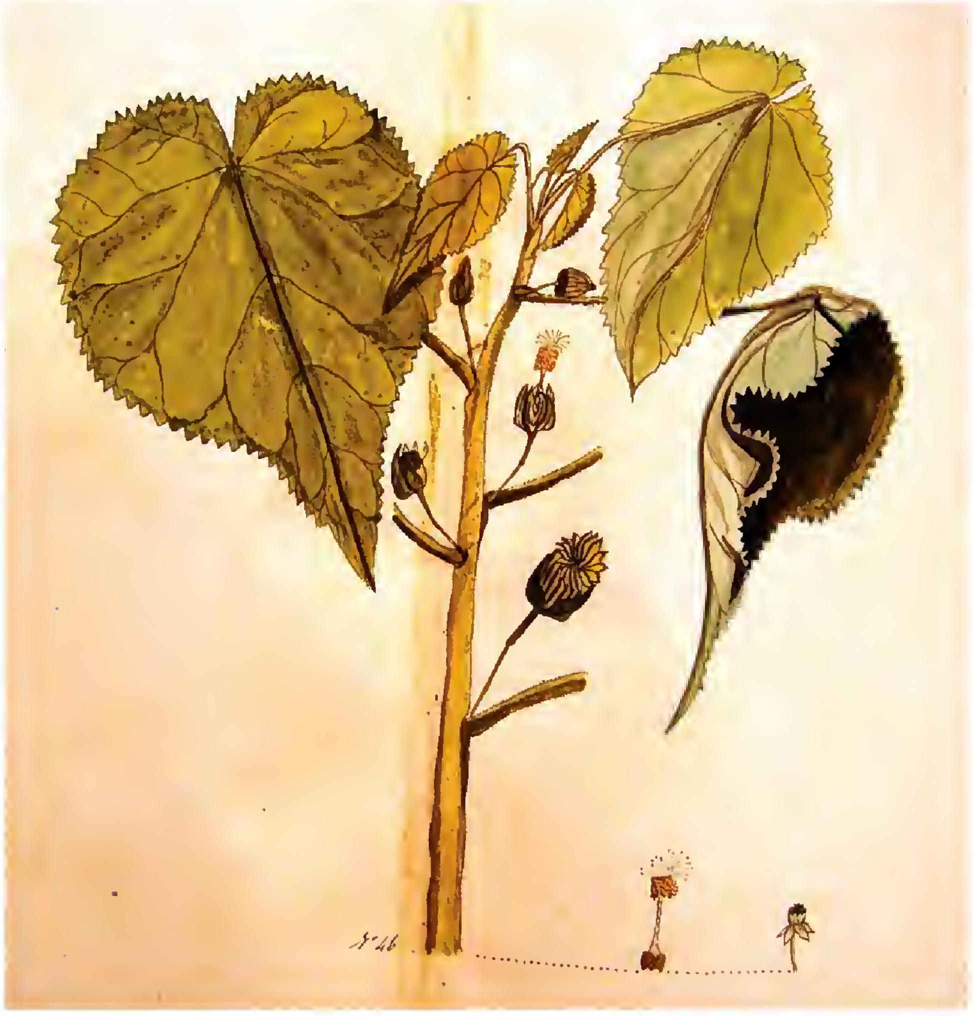

Fig. 10. No.46 *Abutilon julianae* (Malvaceae), a Norfolk Island endemic shrub.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney; DL PXX 1.)

No. 47 *Tylophora biglandulosa* (Endl.) F.Muell. (Apocynaceae) Hoya

47 Asclepias

This is a moderately common rainforest creeper on Norfolk Island, with one large old plant on Phillip Island (Mills 2009). The species is also known from other islands in the southwest Pacific. The watercolour shows the climbing habit of the plant and inflorescences of small flowers, which are coloured pinkish. Pencil notes are the genera ‘Cynanchum vel [or] Asclepias’ and nearby the letter ‘B’; these genera being in the same family. The species was named and described as *Hybanthera biglandulosa* by Endlicher (1833).

No. 48 *Melodinus baueri* Endl. (Apocynaceae) Big Creeper

48 The Creeper on which the Locust makes its first appearance

This endemic vine is also illustrated in drawing No. 20. In addition to a climbing stem and leaves, this painting shows small insects, a species of leafhopper; juveniles and adults are depicted. Neither flowers nor fruit are depicted. The pencil note ‘Apocinoid B’ on this sheet refers to the family to which this genus belongs.

No. 49 *Excoecaria agallocha* L. (Euphorbiaceae) Melky Tree

49 Grows about 30 feet high

This tree grows around the southern coasts of Norfolk Island, where it is often a low-growing, wind-pruned plant. The watercolour illustrates a stem with the thickish leaves of the species and several spikes of male flowers. A pencil note says ‘Excaecaria’. The species grows throughout the southwest Pacific, including northern Australia.

No. 50 *Muehlenbeckia australis* (G.Forst.) Meisn. (Polygonaceae) Shrubby Creeper

50 Nearly about the same size

This species grows as a scrambling shrub or climber and occurs in open areas in and near rainforest; it also occurs in New Zealand. The specific name here meaning ‘southern’, and not referring to the Australian continent. The watercolour illustrates the creeping stem, distinctly shaped leaves and terminal and axillary panicles; see Figure 11. The species was named *Coccoloba australis* by Georg Forster in 1786 based on a specimen from New Zealand collected on Cook’s voyage in 1774; the taxon has been placed in the genus *Polygonum* in the past.

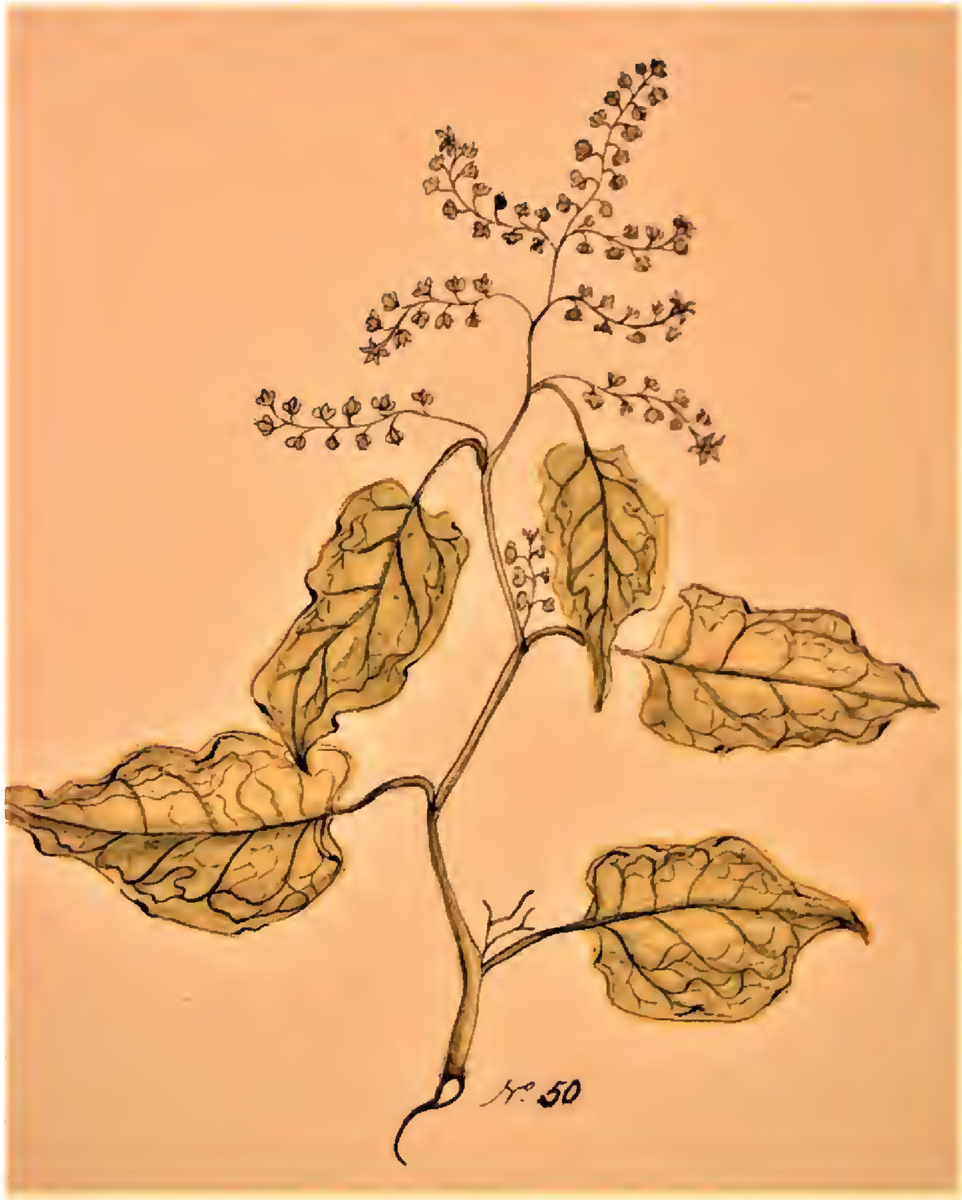

Fig. 11. No.50 *Muehlenbeckia australis* (Polygonaceae), a scrambling creeper shared with New Zealand.
Attributed to John Doody, c.1792. (Mitchell Library, Sydney; DL PXX 1.)

Discussion

The Paterson/Doody material is a most valuable contribution to the study of the flora found growing on Norfolk Island at the time of European settlement. The material represents the first, and certainly the only relatively comprehensive treatment of the non-fern flora, prior to the work of Ferdinand Bauer in 1804-05. Paterson's accompanying notes provide the earliest descriptive and ecological material for many of the plants and although the species are not named in Paterson's notes or on the sheets, and indeed most could not have been at that time, the illustrations in combination with the notes leave no doubt as to the species being referred to in the notes. In addition to their artistic merit, beauty and general interest, the Paterson/Doody material offers some important early insights into the flora of Norfolk Island, prior to its large-scale modification in the first half of the 19th Century.

The 45 indigenous species of trees, shrubs, vines and herbs illustrated represent about one third of the currently recognised non-fern indigenous flora of the Norfolk Island Group. All of the species illustrated are known to science, but two species are now extinct on Norfolk Island, *Solanum laciniatum* (No.15); this drawing of *Solanum laciniatum* is the only record of the species from Norfolk Island; .and *Solanum bauerianum* (No.14); the latter was endemic to both Norfolk and Lord Howe Island and is now extinct. The notes also prove that *Plumbago zeylanica* (No.12) is definitely indigenous to Norfolk Island, a fact that has not always received complete acceptance. *Plumbago* is still found on the remote sea cliffs at Duncombe Bay today, where Paterson states it occurs.

Three interesting inclusions are paintings of species of *Ipomoea* (Nos. 8, 37 and 41), at least two of which could not be indigenous to the island. These species had probably been introduced to the island very early after European settlement, only three years before Paterson arrived. How these exotic plants arrived on the island is not known, perhaps incidentally, such as in contaminated stock feed, or even brought as garden plants. In relation to the potentially indigenous species, given the presence of the above two species, the drawing of *Ipomoea cairica* (No. 41), does not establish beyond doubt that *Ipomoea cairica* is indigenous to Norfolk Island (Mills 2010c). A collection of *Ipomoea cairica* from the Botany Bay (Sydney) foreshore by Robert Brown in 1802 confirms an early presence in the Sydney area.

The recent history of the endemic *Abutilon julianae* (No. 46) is one of literally coming back from near extinction. This shrub had apparently been last collected on Norfolk Island by Robert Laing, the New Zealand botanist, in early 1912. Despite searching in recent years, the plant has not been found growing naturally on Norfolk. Paterson's notes state that only a few plants were found at Far Bay on Norfolk, so it was probably rare there from the earliest time of European settlement. However, following the elimination of Rabbits on nearby Phillip Island in the late 1980s, the plant was found on that island. It has since spread on Phillip Island, and been planted there (Mills 2009); it has also been planted in many places in the national park on Norfolk Island.

The most iconic tree on the island, the Norfolk Island Pine *Araucaria heterophylla*, is not included in the watercolours; perhaps this is because it was already so well-known at the time. The pine is, however, discussed at the beginning of Paterson's written notes.

Conclusion

The watercolour paintings and associated notes attributed to John Doody and William Paterson, respectively, offer a most valuable contribution to the study of the flora of Norfolk Island. The provenance of the notes can be attributed to Lieutenant Governor William Patterson with certainty. The convict John Doody, Paterson's servant during his time on Norfolk Island, almost certainly produced the watercolours discussed in this paper and that are unquestionably associated with Paterson's notes; this can be inferred from the note in Paterson's letter to Banks in 1794.

Paterson never completed his planned Natural History of Norfolk Island, but his notes and the Doody watercolours left us with an invaluable record of the plants of the island as found in the early 1790s. These were prepared four years after the First Convict Settlement was established in 1788, and before there was large scale change to the island environment. Besides their historic importance, we should also appreciate the beauty of convict John Doody's watercolours, which must have been prepared under less than ideal conditions.

Acknowledgments

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Hand-pollination increases seed set in the critically endangered orchid *Thelymitra kangaloonica.*

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Abstract: *Thelymitra kangaloonica* is a listed Critically Endangered sun-orchid (family Orchidaceae) with a highly restricted distribution. In recent years both individual abundance and capsule set rates have been low in this species. The flowers of *Thelymitra kangaloonica* possess some traits associated with autogamy (self-fertilisation) and others associated with entomophily (insect-pollination), however the pollination mechanisms have not been explicitly tested.

This study compared the capsule set rate of flowers cross-pollinated by hand among individuals, against flowers which received no treatment. We found that capsule set rate in hand cross-pollinated flowers was significantly higher than in flowers receiving no treatment (23.1% versus 4.4%). This suggests that *Thelymitra kangaloonica* relies primarily on entomogamy to achieve seed set. Hand cross-pollination may assist management of the species by increasing the number of seeds in the soil seed bank and potentially assist in increasing the population size. In addition, it facilitates seed collection for seed banking and development of an ex-situ population for future population augmentation or translocation.

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Introduction

Thelymitra kangaloonica is a large-flowered sun-orchid (family Orchidaceae) occurring in seasonal sedge swamp habitat on grey silty clay-loam and is currently known from just two swamps near Kangaloon on the Central Tablelands of NSW (Jeanes 2011). Monitoring at the two sites in 2016, 2017 and 2018 recorded a very small flowering population annually (maximum of 18 at a site in a season - DPIE unpublished data) although larger flowering events have been reported historically (D. Wilson anecdotal report). The species is listed as Critically Endangered under both Commonwealth and State legislation because of its small population and very limited distribution.

Sun-orchids only open their flowers on warm, sunny days (Bates 1984) and are known to be pollinated through a range of mechanisms including cleistogamy, mechanical selfing, and insect pollination (Cropper and Calder 1990, Sydes and Calder 1993). Insect-pollinated *Thelymitra* species generally have larger flowers that open freely on sunny days and have compact pollinia that are firmly attached to a functioning viscidium (Cropper and Calder 1990, Sydes and Calder 1993, Edens-Meier *et al*. 2013). In contrast, self-pollinating species tend to have flowers that do not open, or only open tardily on very hot days, and have friable, mealy pollen that does not adhere to the viscidium (Sydes and Calder 1993 and Edens-Meier *et al*. 2013).

Thelymitra kangaloonica is one of seven described taxa within the *Thelymitra aristata* complex (Jeanes 2011). Within this complex, the primary pollination mechanism for three species is entomogamy while the remaining four, including *Thelymitra kangaloonica*, are thought to be autogamous or facultatively autogamous based on pollen structure and coherency, and rates of capsule development (Jeanes 2011).

Flowers of *Thelymitra kangaloonica* have a combination of autogamous and entomogamous traits. Jeanes (2011) noted that the friable, mealy pollen as well as the high capsule set suggest that the species is facultatively autogamous whereas the large, freely opening flower, strong spicy fragrance and the functional viscidium indicate that it is at least capable of entomophily.

Seed collection as part of a conservation project for the species to establish an ex-situ population was planned as part of the NSW Government's Saving our Species Program. However, monitoring of the 14 plants observed in 2016 and 2017 revealed a complete absence of capsule development (DPIE unpublished data). In 2018, in collaboration with the Australian Botanic Garden, Mount Annan, hand cross-pollination was implemented in an attempt to improve capsule development rates to permit collection of seed for propagation. This presented an opportunity to test the impact of hand-pollination on capsule development within an experimental context, and so gain insights into the species' pollination biology. These insights have implications for management actions that may assist the conservation of this species, as we discuss below.

Methods

Study sites

We studied the population of *Thelymitra kangaloonica* at the two sites where the species is currently known near Kangaloon, NSW within the protected WaterNSW Metropolitan Special Area. The sites form part of the Coastal Upland Swamp Endangered Ecological Community also listed under State and Commonwealth legislation.

Population monitoring

Surveys to locate individuals were undertaken at both sites during the flowering period between 29th October and 14th November in 2016, 2017 and 2018. The presence of the species was first detected in Swamp 2 during exploratory surveys in 2017, meaning no surveys were conducted in this location in 2016. Surveys were only conducted on warm, sunny days when flowers were more likely to be open, therefore maximising detection probability. Each swamp was visited on at least three days each year and any flowering individuals were pegged and marked permanently with a thin metal stake and numbered brass label. All known individuals were checked in subsequent years. Non-flowering individuals, present only as an unidentifiable single basal leaf, were not recorded. For each plant the number of flowers per spike was recorded. Flowering individuals were checked weekly post-flowering for at least two weeks to determine if capsules had developed.

Hand-pollination

Hand cross-pollination was undertaken at both swamps in the 2018 flowering season. This was carried out by removing the pollinia from a flower of one individual plant using a new tooth pick, then gently rubbing the pollinia onto the stigma of a flower from a different plant. Only flowers which were open or beginning to open were selected for hand cross-pollination. For each hand pollination event, the individual plant and flower (counted from top down) of the pollen receiver and the pollen donor were recorded. Organza bags were placed over the flowering spike once capsule development was observed or if flowers were no longer active. All cross-pollination events were between individual plants within the same swamp.

Data analysis

Fisher's Exact Tests (Social Science Statistics 2019) were carried out to determine whether observed rates of capsule development differed between hand cross-pollinated and non-hand cross-pollinated flowers. Individual tests were carried out on 2x2 contingency tables for each swamp, as well as on the pooled data across both swamps.

Results

Population monitoring

The population of flowering individuals remained small over the three years of monitoring although it increased slightly at both sites over time (Table 1). No individuals recorded flowering in one year were recorded flowering the subsequent year; however, three individuals flowering in 2017 had a basal leaf but no flowering stem in 2018. This is likely to be an underestimate of total non-flowering individuals, as the leaf is quite cryptic in the swamp vegetation.

Table 1. Number of flowering *Thelymitra kangaloonica* individual plants found at each swamp across the three years of study. Note Swamp 2 was not formally surveyed in 2016.

	No. flowering individuals	
	Swamp 1	**Swamp 2**
2016	1	N/A
2017	5	8
2018	6	18

Pollination monitoring

The 24 flowering plants located in 2018 had a total of 162 flowers, with between 3 and 13 flowers per spike. Some individuals had finished flowering at the time of survey (all flowers on the spike were wilting and turning brown); 16 of the 24 flowering individuals had at least one flower available for cross-pollination. Intact pollinia were present in all individual flowers utilised for hand cross-pollination. The pollinia were observed to be cohesive and well-attached to a sticky viscidium, with which they could be easily removed. A total of 26 flowers across the 16 individuals were hand cross-pollinated (one to three flowers per individual plant). The remaining 136 flowers received no treatment.

A total of 11 flowers across eight plants developed capsules. A greater percentage of hand cross-pollinated flowers developed capsules (22.2% for Swamp 1 and 23.5% for Swamp 2) than untreated flowers (3.4% for Swamp 1 and 4.7% for Swamp 2; Table 2). This was statistically significant for Swamp 2 (Fisher's Exact Test, $P = 0.0346$) but not Swamp 1 ($P = 0.1703$). The comparison was statistically significant for the pooled data ($P = 0.0101$).

Table 2. Comparison of capsule development of hand cross-pollinated versus untreated flowers across the two swamps.

	No. flowers	No. flowers capsule developed	% capsule development
Swamp 1			
Hand-pollinated	9	2	22.2
Untreated	29	1	3.4
Total	38	3	7.89
Swamp 2			
Hand-pollinated	17	4	23.5
Untreated	107	5	4.7
Total	124	9	7.26

Discussion

Seed capsule development was much higher when hand cross-pollination was undertaken compared to when no treatment was applied. In combination with the functional viscidium, cohesive pollen, strong fragrance, and large, freely opening flowers (Jeanes 2011), this suggests that *Thelymitra kangaloonica* is more strongly dependent upon insect pollination than thought by Jeanes (2011).

Jeanes (2011) based his conclusions on the pollination mechanism of *Thelymitra kangaloonica* on analysis of herbarium specimens and discussions with orchid enthusiasts who had observed the species. The "friable and mealy" pollen observed was one of the reasons he suggested that the species was autogamous. In this study we observed that the viscidium was sticky, the pollinia were well-attached and the pollen held together well during transfer between flowers. It is possible that the pollen Jeanes (2011) observed had become "mealy" with age as when we investigated older flowers in the field the pollinia tended to disintegrate when we attempted to remove them with the tooth pick and the pollen within was friable and mealy.

A high level of seed capsule set in the *Thelymitra* genus, as reported by Jeanes (2011), is typically associated with autogamy. Again, Jeanes based his observations on capsule set in *Thelymitra kangaloonica* on preserved herbarium specimens which had high capsule set but were lacking in information on species abundance at the time of collection (Jeanes pers. comm.). In contrast, we observed low seed capsule set rates during a period of low species abundance. This inconsistency in seed capsule set may be a result of variable insect pollination rates based on the size of the floral display in any one season. This is particularly likely if insect pollination is by food deception, rather than olfactory communication, and insect pollinated *Thelymitra* are thought to be primarily food deceptive rather than sexually deceptive (Jones 2006). In a year when many *Thelymitra kangaloonica* are flowering the floral display may be large enough to attract many pollinators to the area leading to high pollinator visitation rates, resulting in high seed capsule set by entomophily. When there are few *Thelymitra kangaloonica* flowering, the display may be insufficient to attract many pollinators leading to low seed capsule set by entomophily. This phenomenon has previously been observed in other orchid species such as *Listera ovata* (Brys *et al*. 2008) and *Myrmecophila christinae* (Parra-Tabla and Vargas 2007). The floral display present is not necessarily limited to flowers of that single species but may include synchronous flowering by other species, typically somewhat similar in appearance. We did not collect data on other flowering species as part of our surveys although the related *Thelymitra ixoides* and *Thelymitra pauciflora* were observed in low numbers in the broader vicinity but not within the swamp habitat of *Thelymitra kangaloonica.*

Insect-mediated and putative cross-pollination has only been confirmed in eight large-flowered *Thelymitra* species. These species are *Thelymitra media* and *Thelymitra aristata*

(Jones 1981), *Thelymitra megcalyptra* (Bernhardt and Burns-Balogh 1986), *Thelymitra antennifera* (Dafni and Calder 1987), *Thelymitra epipactoides* (Cropper and Calder 1990), *Thelymitra ixoides* (Sydes and Calder 1993), *Thelymitra macrophylla* and *Thelymitra crinita* (Edens-Meier and Bernhardt 2014). Generally, pollinators were female native bees of the families Apidae, Colletidae, and Halictidae; although pollen has also been observed on a solitary wasp (*Eurys* species) and hoverfly (*Syrphus damaster*) (Edens-Meier and Bernhardt 2014). We did not observe any likely insect pollinators incidentally while in the field however no targeted surveys were undertaken.

This research does not preclude autogamy occurring in the species. A low number of seed capsules developed in the absence of hand cross-pollination, however we cannot determine if these were pollinated via entomophily or autogamy. In this field study, recently opened or opening flowers were observed to possess cohesive pollinia well-attached to, and easily removed by, a sticky viscidium. This feature, combined with the low rate of capsule set in the absence of hand cross-pollination, suggest entomophily is the dominant mode of pollination and autogamy – if present – is likely to be facultative rather than obligate. A future study comparing the effectiveness of hand-pollination within individual flowers could be undertaken to determine if autogamy is possible but is a low priority given the status of the species.

Seed capsule set and development is not solely determined by pollination (Elliott and Ladd 2002). Production of seed and fruit is costly and resource availability has been demonstrated to limit production in some cases (e.g, Lloyd 1980 and Stephenson 1981). Given that seed capsule set increased with hand-pollination in a season it is likely that seed capsule set is primarily limited by pollination. However, it has been demonstrated that plants can be pollinator-limited within a season but resource-limited over their lifetime (e.g, Montalvo and Ackerman 1987). As no individuals flowering in 2016 or 2017 then flowered the subsequent year, it may indicate that resource availability is limiting reproduction over consecutive years, however further evidence would be required to confirm this. There has been little research into either pollinator or resource limitations in the *Thelymitra* genus. Not all individuals flower each year so multi-year studies, tracking individuals' reproductive status and outcomes as well as environmental conditions, may help explain some of the high variability observed in flowering events and seed capsule set.

As a critically endangered orchid, the small, flowering population size and very low levels of natural capsule set over the last three years is a concern. It is likely that seed production is the only means of population increase in this species as it does not appear capable of producing multiple replacement tubers each year. This is based on the lack of any clumping of individuals observed over the last 3 flowering seasons, as seen in some other species such as *Diuris arenaria* (K. Sommerville unpublished data). The success of hand cross-pollination in increasing capsule set and development offers a potential management action to benefit the species. Increased seed production through hand-pollination would lead to an increased soil seed bank and potentially assist in increasing the population size as well as allow for seed collection for seed banking and development of an ex-situ population for future population augmentation or translocation.

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High macropod populations at Look At Me Now Headland, North Coast NSW: implications for endangered *Themeda triandra*-grasslands on coastal headlands

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Abstract: High grazing pressure from over-abundant macropods (kangaroos) is perceived to have a detrimental impact on biodiversity. Studies have shown potential changes in state and retardation of degraded vegetation recovery while other investigations have shown correlations with increased floristic diversity. The responses of grasslands to high impact macropod grazing may not be universal. Endangered *Themeda triandra*-dominated grasslands, on coastal headlands of New South Wales (NSW) and the associated threatened flora are thought to be negatively affected by high macropod grazing.

We assess these assumptions via a comparative investigation across 46 headlands (467 plots) on the North Coast of NSW, and a BACI (Before and After Control Incident) design grazing exclusion experiment at a particularly significant site. We compare floristic richness, species density, evenness, Shannon H, Whittaker Beta Diversity, occurrence of listed threatened flora, average sward height and macropod density.

Look At Me Now Headland (LAMN), between Coffs Harbour and Woolgoolga has one of the highest recorded population densities of macropods. Here 16 permanent plots were placed with grazing exclusion cages erected around half. Sampling occurred annually (October-November) for four consecutive years (2015-2018). Under high macropod grazing pressure LAMN Headland was found to have the highest scores for total richness, species density, species diversity and moderate to high values for species evenness and beta diversity. Within grazing exclusion plots the sward height increased significantly and was associated with a significant decrease in species density, beta and alpha diversity.

Our results indicate that macropod grazing, even at the highest intensities, may be beneficial to floristic species diversity within the endangered *Themeda*-grasslands of coastal headlands and seacliffs within the North Coast Bioregion of NSW; our broader comparative study would suggest that this may also be the case on other headlands.

Key words: grazing management, monitoring, threatened community, threatened species, sward height, species diversity, richness, BACI.

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Introduction

Uncontrolled high numbers of grazing macropods (kangaroo) are thought to cause substantial changes in vegetated communities often leading to cascading changes in state (Flemming et al., 2012; Morgan et al., 2017). High densities of macropods have been known to cause detrimental impacts on soil health, fauna habitat, the recovery from fire and recovery of degraded vegetation (Meeers & Adams, 2003; McIntyre & Tongway, 2010; McIntyre et al., 2010; Howland et al. 2014). Overabundant macropods are viewed as generally posing a threat to the conservation and restoration of native vegetation remnants (Read; https://www.esa2019.org.au/symposia-at-esa19/). While negative impacts on flora have been shown in some instances, these impacts may not be universal and evidence suggests that different outcomes may occur within different vegetative systems (Hunter & Hunter 2017a). If differences in impact exist it is important that these are looked at, so that more nuanced and targeted management actions are made appropriate to each system.

Themeda-dominated assemblages on coastal headlands in New South Wales (NSW) are currently listed as an Endangered Ecological Community- *Themeda*-grasslands of coastal headlands and seacliffs within the North Coast Bioregion of NSW (NSW *Biodiversity Conservation* Act 2016; http://ww.environment.nsw.gov.au/determinations/ThemedaGrasslandSeacliffsEndSpListing.htm). These communities exist on island-like rocky headlands primarily on basalt substrates, but they are not restricted to this rock type. A total of 108 ha of the community is thought to be extant within NSW of which 72% (78 ha) occurs within conservation reserves (J.T.Hunter *unpublished mapping* 17/03/2019). Though described as grasslands, most occurrences are a mosaic of co-dominant *Themeda triandra* and a variety of prostrate shrubs sometimes referred to as grassy prostrate heaths (Hunter & Hunter 2017a). *Themeda*-assemblages on headlands and seacliffs are thought to be endangered by encroachment of taller shrubs (native and non-native), invasive weeds, inappropriate fire regimes, inappropriate plantings, agriculture, foot traffic and grazing by native and non-native herbivores (Adam et al., 1989; Kenney, 2012; Lunt et al., 2010). Many of these threats have been proposed without any research to corroborate how much these factors may negatively impact on the grasslands. Recent research suggests that a more nuanced understanding may be required and that some suggested threatening processes may have benefits to the grassland, at least under specific scenarios, and that a blanket cessation of certain threats may be more detrimental (Hunter & Hunter, 2017ab; Hunter, 2018).

Eastern Grey Kangaroos (*Macropus giganteus*) are common and abundant within peri-urban communities of coastal NSW and are often found in high numbers on some grassy headlands. The northern beaches of Coffs Harbour, and in particular the Emerald Beach area, has been designated as a kangaroo hotspot (Henderson et al., 2017). One of the reasons for such high numbers include the upgrade of the highway which has precluded movement of macropods out of the coastal areas and into the hinterlands; however, other explanations are also likely. Henderson et al. (2017) investigated the population sizes of kangaroos in the northern beaches area of Coffs Harbour and found that Emerald Beach area (between Coffs Harbour and Woolgoolga) which includes Look At Me Now Headland (LAMN) and Dammerels Headland had kangaroo populations more than twice as high as any other location in the region (4.87 individuals ha^{-1}). Similar kangaroo densities (5 individuals ha^{-1}) in Goorooyarroo and Mulligans Flat Nature Reserves (in the Australian Capital Territory) have been considered to have had detrimental impacts to soil health, fauna habitat and recovery of degraded vegetation (McIntyre et al., 2010; ACT DTMS & ACT PCL, 2010). Of the Coffs Harbour headlands WIRES et al. (2016) suggested that the population densities were detrimentally effecting biodiversity values, specifically that macropods, through direct consumption and trampling were a medium to high threat impacting negatively on threatened flora species and the threatened *Themeda*-dominated coastal headland assemblages. In spite of these claims no actual data existed to substantiate the negative impacts on the endangered *Themeda*-dominated grassland or the threatened species on these headlands.

In contrast, correlative studies have indicated that events that reduce *Themeda triandra* sward height and dominance may lead to increased floristic diversity at the local and landscape scale, and retention of threatened flora species populations on coastal headlands (Hunter, 2016; Hunter & Hunter, 2017ab; Hunter 2018). In particular, analyses by Hunter and Hunter (2017a) indicated that increased grazing pressure from macropods, even at the highest densities, was associated with increased floristic species and trait diversity within *Themeda*-dominated assemblages of the Coffs Harbour region.

LAMN Headland is a major location for the conservation of the endangered *Themeda*-grasslands on coastal headlands and designated Saving Our Species site for the conservation of the grasslands, the threatened shrubs *Zieria prostrata* J.A. Armstrong and *Pultenaea maritima* de Kok and a known site for *Senecio spathulatus* A.Rich. and *Thesium australe* R.Br. (http://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-program; Cohn, 2004; Hunter, 2016; Hunter & Hunter, 2017ab). LAMN Headland provides an interesting case study of a headland with a long history of high macropod abundance on a location that is a key area for the conservation of endangered grassland and listed threatened flora species.

Here we test the effects high macropod grazing pressure on the floristic diversity of *Themeda*-dominated assemblages at LAMN Headland. Firstly, we compare biodiversity measurements (richness, rarity, species density, species diversity) obtained from occurrences of *Themeda*-dominated assemblages on headlands. Secondly, we more directly investigate the effects of grazing by tracking the changes across a grazing exclusion experiment using a Before and After Incident (BACI) design over a four-year period.

Methods

Study area

Themeda-dominated assemblages on coastal headlands in eastern Australia form an intricate mosaic of grass and prostrate heath and is best described as grassy prostrate heath (Hunter & Hunter, 2017a). Vegetation data was collected from headlands with *Themeda*-dominated assemblages in the North Coast Bioregion of NSW, Australia, the broader study area covering approximately a 530 km stretch of coastline from Byron Bay south to Gosford (-28.5469° to -32.6638°). The climate of the region is sub-tropical with mean annual rainfall of 1345-1737 mm, mean maximum annual temperatures from 23.4-27.6° C and mean minimum of 9-14.0° C. LAMN Headland at Emerald Beach, between Coffs Harbour and Woolgoolga and the adjacent Dammerels Headland were chosen for a BACI (Before and After Control Incident) design grazing exclusion experiment (both headlands are now referred to collectively as LAMN).

Vegetation and plot data

On 46 coastal headlands we collected data from 467 vascular floristic survey plots, each 2 x 2 m dimension placed randomly within *Themeda*-dominated assemblages (http://www.givd.info/ID/AU-AU-003). The survey was conducted over spring and early summer (November to February) from 2015-2018. Species nomenclature follows PlantNET (http://plantnet.rbgsyd.nsw.gov.au/; accessed January 2017). Vascular plant taxa were scored using overlapping percent cover and frequency. Frequency was determined by dividing the plot into 16 subplots (50 x 50 cm) where the rooted presence and absence of each species was scored in each subplot. A drop plate 10 cm in diameter was attached to a metal ruler and used to record the height of standing biomass of the ground layer vegetation at five random locations within each plot.

During the general survey, the intensity of macropod grazing was assessed via visual observation of live animals, and observed amount and age of macropod dung on headlands. A score from none (no observed animals or dung), **low** (1 piece of macropod dung within a 2 m radius), **moderate** (2-5 pieces of dung within a 2 m radius), **high** (more than 5-10 pieces of dung within a 2 m radius and residential animals seen), **very high** (large resident colonies seen with 10-30 pieces of dung) and **extreme** being more than 30 pieces was allocated to each plot.

Accurate assessment of macropod population sizes was beyond the scope of this project and we acknowledge a number of issues relating to the short-term nature of our macropod observations, and the use of dung which can decay at different rates depending on weather (Johnson & Jarman, 1987). We also acknowledge that observations were only made on a one-time basis; the results can only be of a generalised nature.

Within the LAMN headlands sixteen plots were chosen with eight randomly allocated total grazing exclusion cages. Surveys were conducted in the manner discussed above in November 2015, October 2016, November 2017 and November 2018. Grazing exclusion fencing was placed around and over the top of exclusion plots in December of 2015 after the first survey (Fig. 1). Exclusion cages were designed to minimise the visual impact for local residents and tourists.

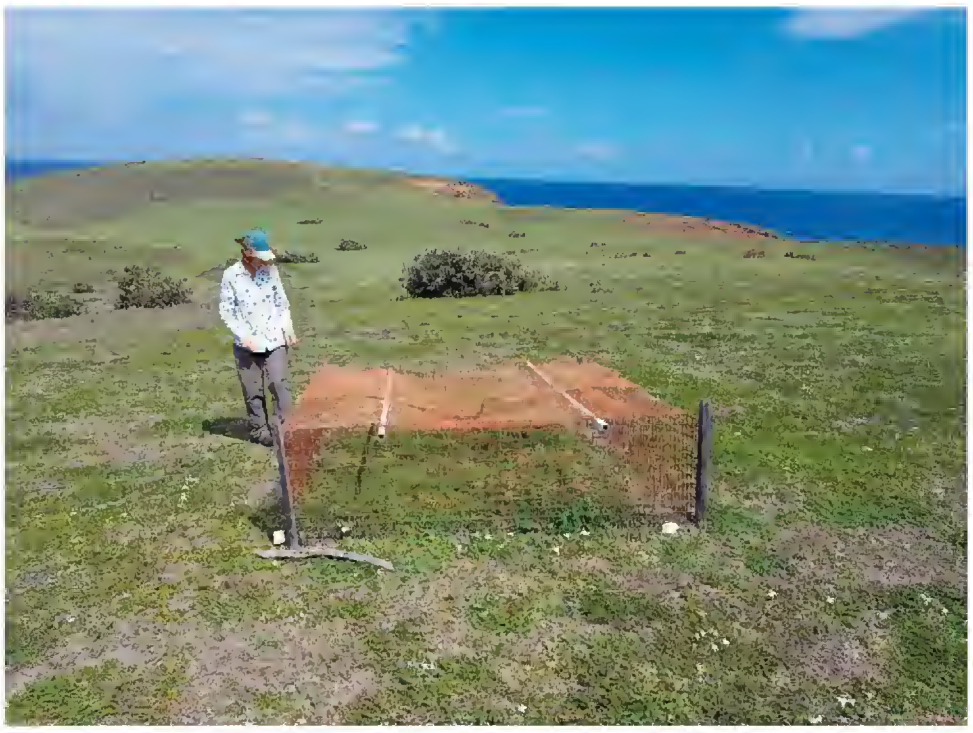

Fig. 1. Example of grazing exclusion cage on Look At Me Now Headland near Coffs Harbour in the NSW North Coast Bioregion.

Statistical analysis

For each spatial and temporal plot placed on LAMN the sward height of the groundlayer, floristic species density (species per plot), Shannon H diversity and summed frequency scores were calculated. Total species richness for each treatment within *Themeda*-dominated assemblages was also collated. Shannon H, species evenness, turnover, total frequency and statistical comparisons between biomass height were calculated within PAST version 3 (Hammer et al., 2003).

The relative interaction index (RII) of Armas et al. (2004) was used to compare the frequency of individual species (out of 16) in plots before erection of exclusion cages and the same plots three years after the erection cages. RII was calculated using $RII = N_{after}-N_{before}/N_{after}+N_{before}$, N equals the frequency score of individuals (out of 16) found in plots before erection of exclusion cages and against plots after caging. The RII score ranges from -1 to 1 with positive scores indicating a positive effect on the frequency of species by grazing exclusion. Before calculation of RII species with only one observation were removed from the dataset. Similarity percentage analysis (SIMPER) identifies the species driving differences between selected types. SIMPER using the Bray–Curtis similarity measure (Hammer et al., 2003) was used to identify taxa contributing most to the Bray-Curtis separation of exclosure and control plots at the final year of sampling (2018).

PERMANOVA (permutational MANOVA) within PRIMER-e (version 7.0.13; Quest Research Limited; Ivybridge, Devon, UK) was performed on data averaged over year and treatment (both considered fixed variables with treatment nested within year). Permutations were conducted with 9999 iterations after square root transformation of the data and Bray-Curtis transformation. Interactions between year and treatment were assessed.

Results

Comparison between headlands

Across the 46 headlands the LAMN headlands were found to have the highest observed macropods densities and highest observed grazing intensities, which corresponded with the lowest average recorded groundlayer sward height (Table 1). The highest flora species richness for *Themeda*-dominated communities was recorded at LAMN (Table 1). The highest number of recorded threatened flora species, highest species density, highest average plot richness and highest average Shannon H diversity score all were obtained at LAMN (Table 1). The highest evenness score occurred at Diggers Point with LAMN had an average score for evenness (Table 1). The highest score for beta diversity occurred at Minnie Waters. LAMN had a higher than average score for Whittakers beta diversity (Table 1).

Table 1. Select floristic attributes for *Themeda*-dominated assemblages within the NSW North Coast Bioregion with macropod grazing. Headlands ordered by Macropod density. Highest scores are highlighted along with the lowest average sward height.

Headland	**Macropod density**	**Average sward height cm**	**Native richness**	**Threatened Species no**	**Species density (Average)**	**Shannon H Average**	**Evenness Average**	**Whittaker Beta**
Look At Me Now	**Extreme**	**4.2***	**70***	**4***	**8-24 (15)***	**2.41***	0.76	2.74
Dammerels Headland	Very High	8.1	41	3	5-19 (12)	2.16	0.73	2.08
Boambe Headland	High	26.5	43	2	6-14 (10)	1.94	0.71	3.27
Boomerang Point	High	15.4	25	1	12-16 (14)	2.17	0.63	0.79
Diggers Camp	High	15.0	24	1	4-15 (7)	1.50	0.67	2.25
Hat Head	High	10.9	30	1	11-17 (13)	2.25	0.74	1.13
Kemps Corner	High	9.8	32	0	11-18 (14)	2.33	0.73	1.15
Macauleys Headland	High	32.5	46	2	5-14 (8)	1.74	0.76	**4.41***
Woolgoolga Headland	High	19.5	22	1	8-15 (11)	2.00	0.70	1.00
Bare Bluff	Moderate	16.4	42	2	5-20 (11)	2.29	0.69	1.77
Charlotte Head	Moderate	14.4	14	0	7-8 (8)	1.54	0.63	0.87
Darkum Rocks	Moderate	16.3	18	1	7-10 (9)	1.88	0.73	1.00
Arrawarra Headland	Low	21.5	32	2	7-19 (11)	1.96	0.71	1.73
Big Hill Point	Low	14.1	15	0	3-11 (8)	1.62	0.71	0.80
Bonville Headland	Low	12.4	16	2	4-11 (8)	1.62	0.70	1.09
Booti Hill	Low	30.5	14	0	6-12 (9)	1.84	0.75	0.56
Bunker Headland	Low	24.7	13	0	4-8 (10)	1.53	0.76	1.05
Camden Head	Low	14.6	30	0	5-18 (12)	2.05	0.76	1.61
Cape Hawke	Low	50.5	9	0	6-8 (7)	1.68	0.78	0.29
Corumbirra Point	Low	16.9	29	2	7-14 (11)	1.93	0.66	1.70
Crescent Head	Low	16.0	23	1	12-16 (14)	2.31	0.72	0.64
Diggers Headland	Low	21.7	11	1	7-8 (8)	1.81	0.77	0.38
Diggers Point	Low	17.2	22	3	7-18 (11)	2.13	**0.81***	0.77
Elephant Head	Low	17.7	13	0	4-11 (9)	1.69	0.69	0.96
Grants Head	Low	21.3	20	0	6-18 (12)	2.02	0.73	0.67
Grassy Head	Low	27.9	23	1	5-9 (7)	1.67	0.76	2.20
Green Bluff	Low	17.0	18	1	4-13 (8)	1.76	0.76	1.22
Lennox Headland	Low	20.2	9	0	2-7 (4)	1.06	0.75	1.61
Middle Head	Low	46.8	16	0	13 (13)	2.16	0.67	0.23
Minnie Waters	Low	34.7	18	1	5-12 (9)	1.70	0.65	1.00
Mullaway Headland	Low	22.7	60	1	5-20 (11)	1.93	0.67	3.46
Ocean View Headland	Low	17.9	68	1	5-18 (11)	1.97	0.67	3.24
Point Plummer	Low	13.3	20	0	10-12 (10)	1.97	0.68	0.78
Queens Head	Low	13.8	20	0	15-15 (15)	2.37	0.72	0.27
Racecourse Head	Low	19.4	23	0	8-15 (12)	2.17	0.73	0.87
Red Rock	Low	7.2	15	1	3-9 (6)	1.44	0.73	1.40
Scotts Head	Low	20.1	17	0	3-13 (7)	1.53	0.69	0.94
Seal Rocks	Low	24.3	11	0	7-10 (9)	1.73	0.67	0.53
Treachery Headland	Low	19.5	13	0	3-8 (5)	1.44	0.73	1.40
Yagon Gibber	Low	19.9	10	0	6-7 (7)	1.57	0.75	0.54
Bald Head	None	12.4	16	0	7-14 (11)	2.10	0.80	0.50
Broughton Island	None	42.9	21	0	5-11 (9)	1.87	0.75	1.36
Crowdy Head	None	22.4	11	0	3-8 (6)	1.73	0.67	0.53
Diamond Head	None	21.7	31	1	13-20 (16)	2.42	0.70	0.90
Flat Top	None	18.9	15	0	12-13 (13)	2.31	0.80	0.20
Forster	None	17.9	11	0	8-9 (9)	1.73	0.67	0.53

BACI grazing exclusion

A total of 86 taxa were found within plots over the course of the investigation of which 66 were found within control and 50 within exclusion plots in the final year of sampling (2018). The sward height increased significantly from an average of 4.2 cm across all plots before erection of cages to 28 cm after three years of grazing exclusion (Fig. 2; Fig. 3). Initially there was no statistical difference between species density scores within treatments at the start of the experiment but in each subsequent observation after exclusion plots were erected species density decreased significantly in exclusion plots (Fig. 4). In contrast control plots remained statistically stable before increasing significantly in 2018 (Fig. 4). Average species density (richness within plots) declined by more than half within grazing exclosures over the observation period. The total number of species recorded across each treatment was found to vary over the observation years but in general was found to decline within exclosure plots and remain comparatively stable within control treatments (Fig. 5). As with species density, Shannon H was not significantly different between treatments in 2015 but decreased significantly each year since fencing, while control plots remained stable before an increase in the final year (Fig. 6). The summed frequency of all species recorded within plots was again not statistically significantly different between treatments in 2015 but was found to decrease significantly yearly in the exclosure plots and overall remain relatively stable within control plots (Fig. 7). The frequency of recorded *Themeda triandra* observations was found to remain relatively stable within control plots and was found to remain stable across years until the final observation in exclosures whereby the overall frequency of *Themeda triandra* was found to increase (Fig. 8). Whittaker's beta diversity within the final year of observation was found be higher within grazed plots (0.7341) compared to ungrazed plots (0.66957). The number of new species found colonising plots over the four years of observations was greater within grazed treatments (Fig. 9).

PERMANOVA results indicated that there was no significant floristic difference between treatments prior to cages being erected (2015 $p = 0.8368$) or one year after their erection (2016 $p = 0.5704$). Two years after cages were erected a near significant difference between treatments was found (2017 $p = 0.0688$) with a highly significant difference between treatments being found three years after erection of cages (2018 $p = 0.0033$).

Table 2. List of plant species found within grazing exclusion plots on LAMN Headland and relative interaction index (RII) score. RII varies from -1 to 1 with negative scores indicating a reduction in frequency after the implementation of three years of grazing exclusion (2018). Introduced species are indicated by '*'. Listed threatened species are indicated by '^{R}'.

Species	Score
Brunoniella australis	1
Dianella revoluta	1
Einadia hastata	1
Gonocarpus hirtus	1
Goodenia bellidifolia	1
Hydrocotyle hirta	1
Lomandra multiflora	1
Paspalidium constrictum	1
*Paspalum urvillei**	1
Thysanotus tuberosus	1
Tricoryne anceps	0.75
Hybanthus stellarioides	0.615385
Themeda triandra	0.084746
Podolobium scandens	0
Pimelea linifolia	-0.02941
Lobelia anceps	-0.17647
Cynodon dactylon	-0.25
Poranthera microphylla	-0.25926
Polymeria calycina	-0.30233
Pratia purpurascens	-0.33333
Oxalis perennans	-0.35714
Senecio spathulatus^R	-0.38462
Zoysia macrantha	-0.46269
Hibbertia vestita	-0.5
Viola banksii	-0.51724
Goodenia rotundifolia	-0.6
Mitrasacme paludosa	-0.63636
Schoenus apogon	-0.74468
Hypochaeris radicata	-0.91667
Carex breviculmis	-0.93103
*Anagallis arvensis**	-1
Centipeda minima	-1
Dichondra repens	-1
*Eragrostis interrupta**	-1
Gonocarpus humilis	-1
Hydrocotyle laxiflora	-1
Isolepis cernua	-1
Lachnagrostis filiformis	-1
Lomandra longifolia	-1
Ottochloa gracillima	-1
*Paspalum dilatatum**	-1
Samolus repens	-1
Schoenus nitens	-1
Spiranthes australis	-1
Stackhousia viminea	-1
*Taraxacum officinale**	-1

Of the 46 species within the exclusion plots, 31 were found to have decreased in abundance by November 2018 with only 15 species found to increase over this time (Table 2). *Themeda triandra* was found to have the smallest increase in frequency (RII score 0.085) (Table 2). Of these 15 species that increased in the exclosure plots, 11 did not contribute to SIMPER separation of the treatments; the remaining four had a slightly higher overall frequency within control plots largely due to these species being in low frequency and being new colonisers rather than increasers which also were found within the control plots. One introduced species was found to have increased while one rare species and four introduced species declined in exclosure plots (Table 1). *Themeda triandra* was not found within SIMPER outputs indicating that this dominant species had no impact on the significant separation of the treatments within the final year of observations. All threatened species (*Senecio spathulatus, Zieria prostrata, Pultenaea maritima*) except *Thesium australe* (which was not visible at the final survey) had a higher relative frequency within control plots and contributed small percentages to the Bray-Curtis separation of the treatments (Table 2). Three introduced taxa also made contributions to the Bray-Curtis difference in treatments (in decreasing order: *Hypochaeris radicata, Lysimachia arvensis, Conyza bonariensis*) with higher frequency within control plots, although *Paspalum mandiocanum* was more prevalent in exclusion plots (Table 2).

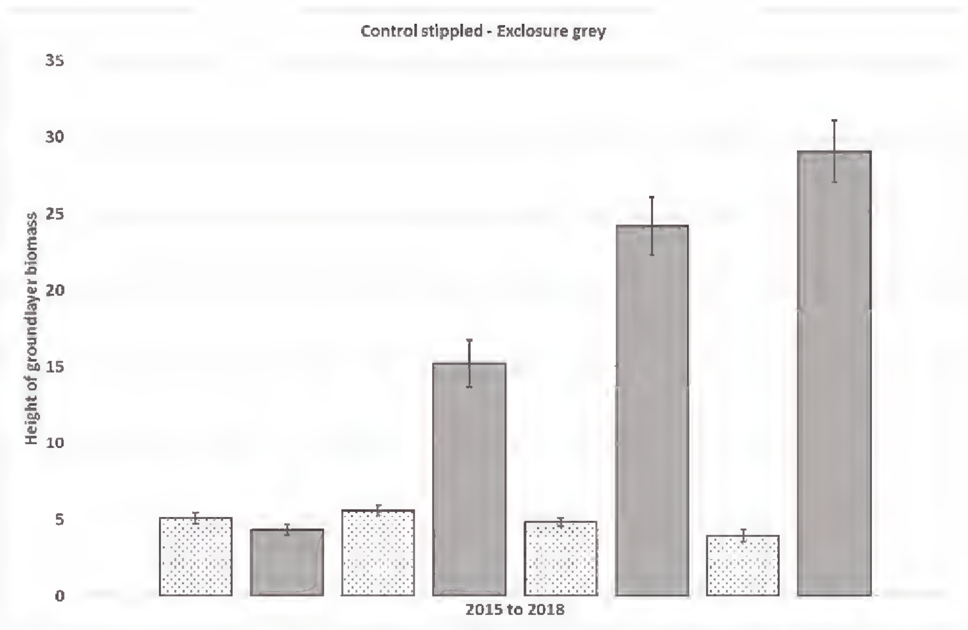

Fig. 2: Bar chart showing height of ground layer vegetation and standard error comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

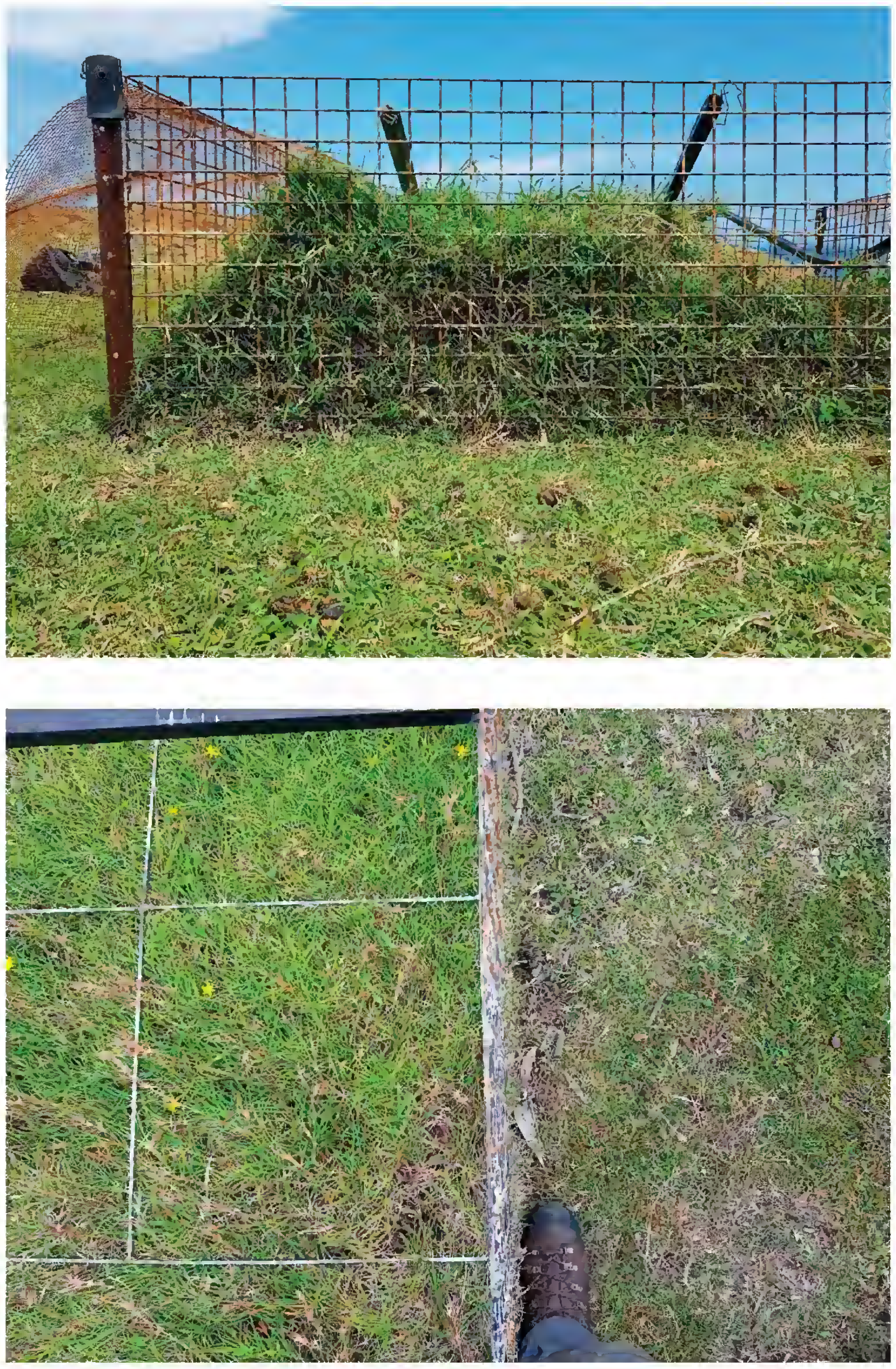

Fig. 3. Photographs of exclusion plots and biomass changes after two years of grazing exclusion.

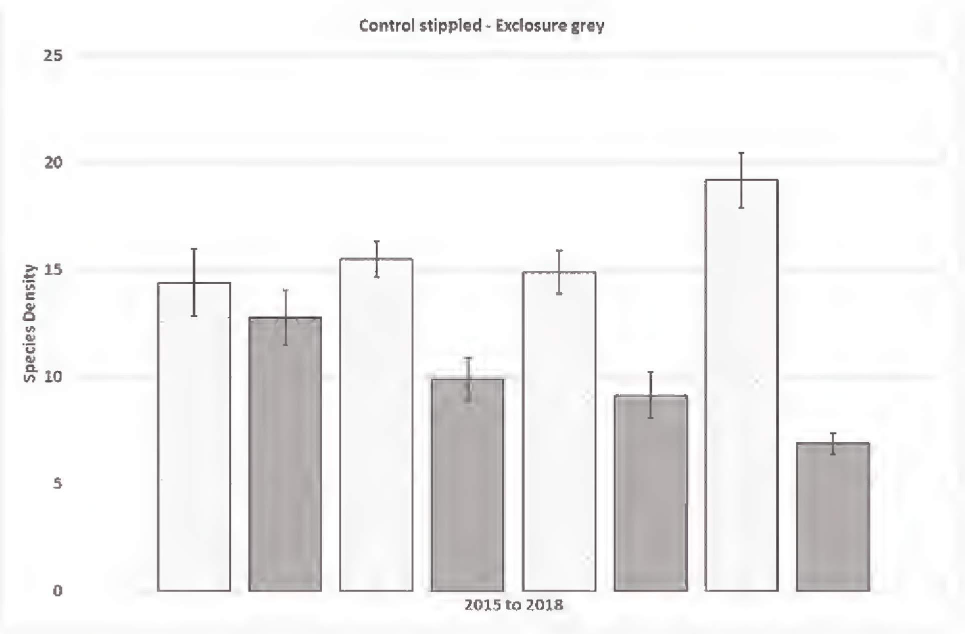

Fig. 4: Bar chart showing height of species density (number of species per plot and standard error comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

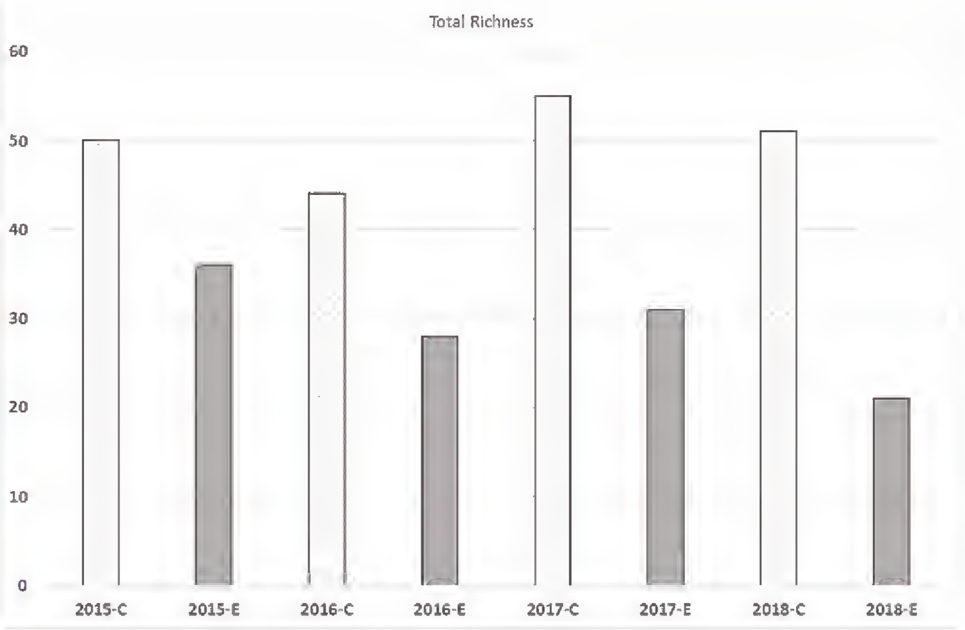

Fig. 5: Bar chart total species count found across all plots within control and exclusion treatments before erection of cages (2015) and for three years of grazing exclusion (2016-2018), Control (C) and Exclusion (E).

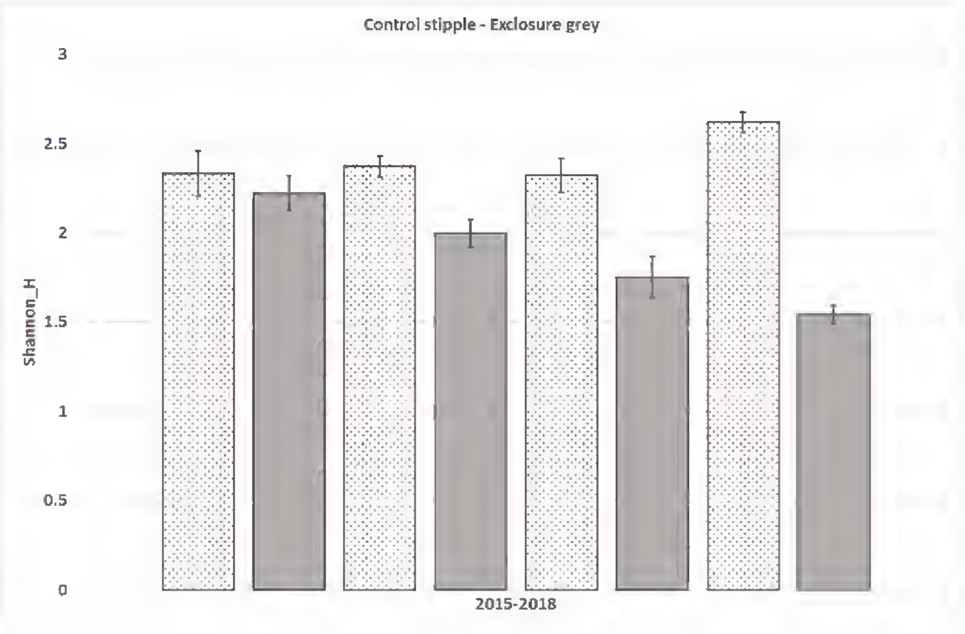

Fig. 6. Bar chart showing species diversity (Shannon H) and standard error comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

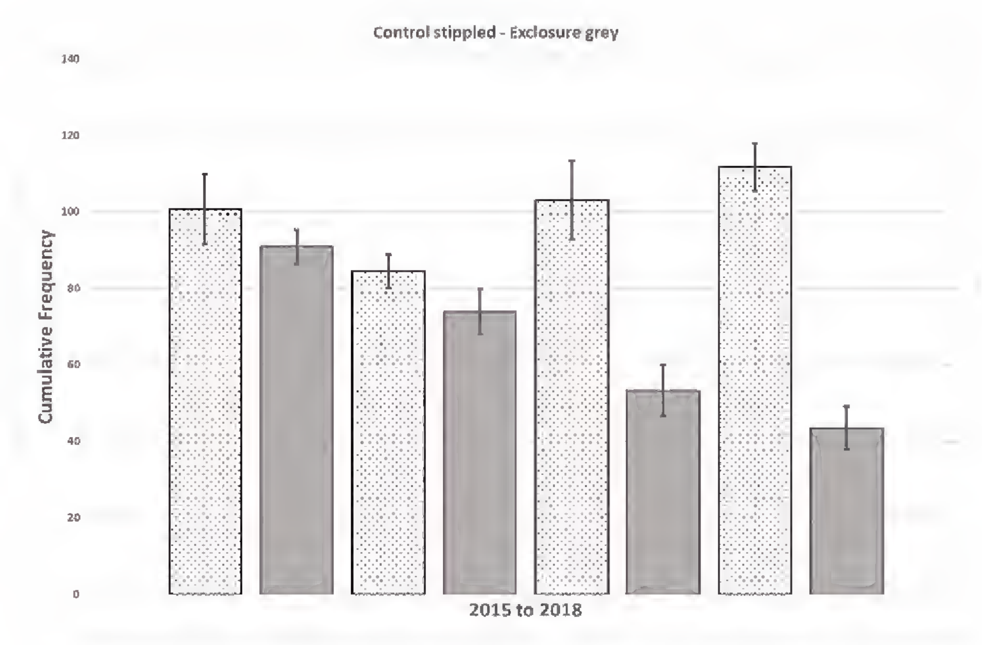

Fig. 7: Bar chart showing summed total frequency of all species found and standard error comparison for control and exclusions plots before erection of exclusion cages (2015) and for three years of grazing exclusion (2016-2018).

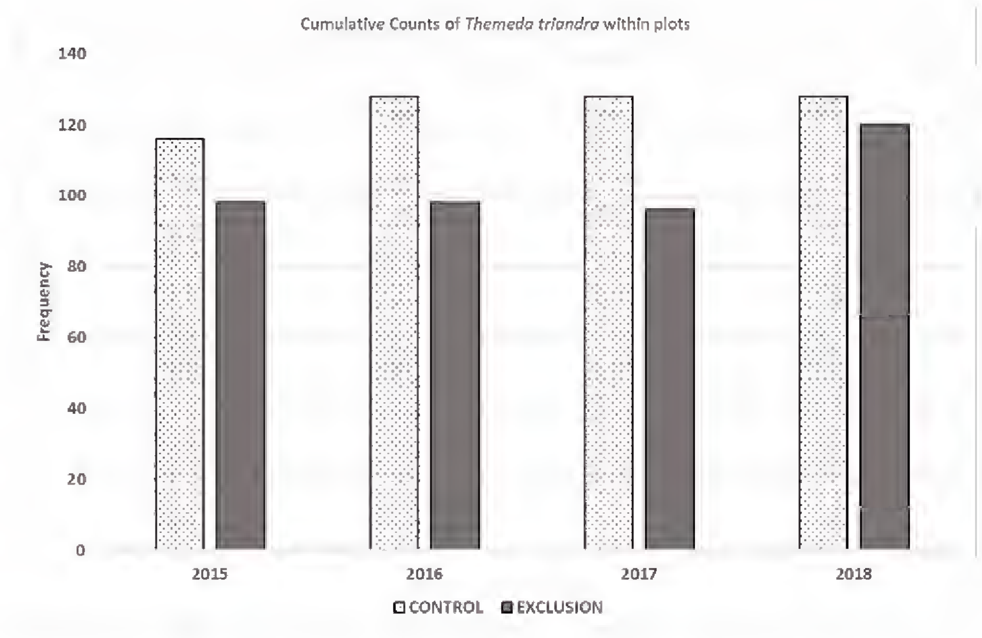

Fig. 8: Cumulative frequency of *Themeda triandra* comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

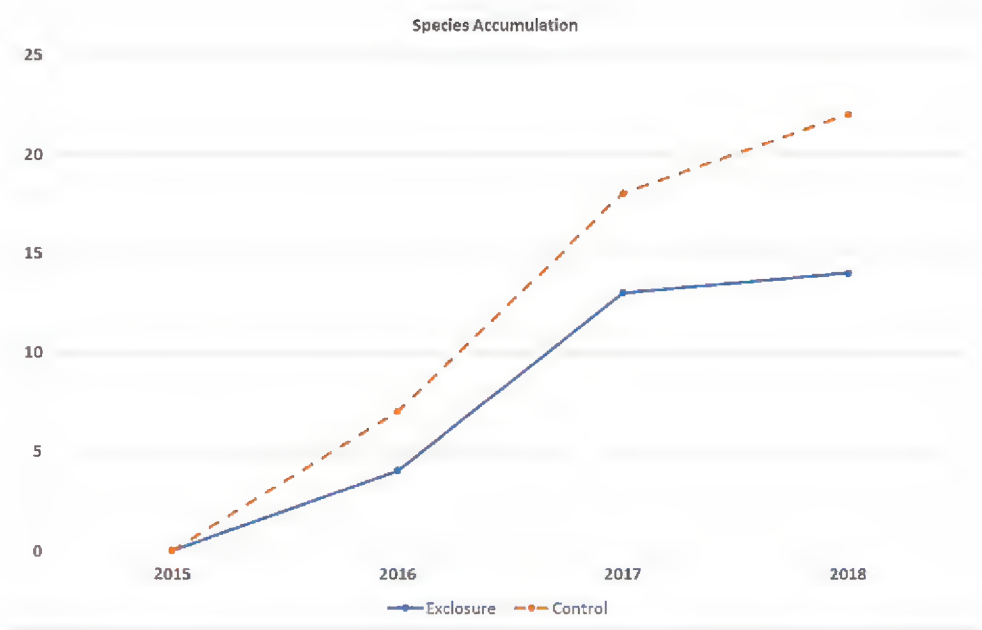

Fig. 9: Number of new species found within exclosure and control plots during the course of four years of monitoring.

Discussion

Our experimental plots confirmed that over the four years, at least for the LAMN headlands (LAMN Headland and nearby Dammerels Head) the longer macropods were excluded, the higher the sward height became at the expense of floristic diversity (alpha, beta and gamma) and numbers of individuals. Plot species richness, species diversity, turnover between plots (Whittakers beta diversity), new species colonisation (species accumulation) and the number of individuals was found to decrease significantly within ungrazed plots and the two treatments diverged to a point that they were statistically different floristic assemblages. Importantly, these changes were not due to any appreciable change in *Themeda triandra* frequency across treatments. *Themeda triandra* remained a dominant entity in both heavily grazed and grazing exclusion sites, in terms of frequency and cover, and was not found to contribute to Bray-Curtis separation of treatments. These results are in agreement with correlative analyses performed by Hunter and Hunter (2017a) who showed macropod grazing was significantly associated with increased floristic and trait diversity. Hunter and Hunter (2017a) and Hunter (2018) also highlighted that interference in *Themeda triandra* overdominance by any means (e.g. grazing, wind shear, competition, interference) was correlated with increases in floristic alpha, beta and gamma diversity.

Eldridge et al. (2003) suggested that 10-20 years was likely to be necessary for ecosystem change to occur as a result of grazing exclusion. However, in our results statistically significant divergence occurred within the treatments by the fourth year. The reasons for this rapid change could be that macropod grazing is not synonymous with grazing by introduced species, or just the inherent differences of this system. It may also be due to the particular defining, and therefore magnitude, of ecosystem change. Within our system heavily grazed and ungrazed were still largely dominated by *Themeda triandra* and in general though the same species occurred across all treatments, the grazing exclusion plots were species poor, and reduced in numbers of individuals. Thus, these changes though significant (p = 0.0033) may not constitute the ecosystem change or trophic modification generally looked for in other investigations (Morgan et al. 2017).

Having headlands with areas that are grazed at various intensities (including ungrazed) is likely to increase the heterogeneity of grassland types on these headlands, thus increasing overall diversity. Our results would suggest that some level of macropod grazing is important within *Themeda*-dominated assemblages on headlands in order to maintain floristic diversity at the local patch, between patches and across the landscape, but importantly, even at the highest macropod pressure, these benefits are maintained. As has been shown by other studies these results are unlikely to be universal within other grassland systems (Meeers & Adams, 2003; McIntyre & Tongway, 2010; McIntyre et al., 2010; Howland et al., 2014). Our study highlights the need to investigate the differences in responses of vegetation assemblages even though they may be dominated by similar species (*Themeda triandra*).

Table 3. SIMPER analysis based on Bray-Curtis similarity using the final 2018 survey data for LAMN Headland. Species are listed in decreasing order of contribution to the Bray-Curtis difference between exclosure and control-grazed plots. Introduced species are indicated by ‘*’. Listed threatened species are indicated by ‘^{R}’

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean Frequency Exclosure	Mean Frequency Control-grazed
Pimelea linifolia	5.429	8.576	8.576	4.14	8.89
Viola banksii	4.636	7.323	15.9	2.57	6.67
Polymeria calycina	4.395	6.943	22.84	5	6.33
Poranthera microphylla	3.944	6.23	29.07	0.143	4.89
Zoysia macrantha	3.906	6.17	35.24	2.43	4.22
Oxalis perennans	3.445	5.442	40.68	0.857	4.44
Goodenia rotundifolia	3.189	5.038	45.72	0	4.11
Schoenus apogon	2.975	4.699	50.42	0.714	3.56
Hybanthus stellarioides	2.397	3.786	54.21	0.714	3.33
*Hypochaeris radicata**	2.197	3.47	57.68	0	3.44
Lobelia anceps	2.067	3.265	60.94	2.57	0.444
Carex breviculmis	1.95	3.081	64.02	0	2.78
Hibbertia vestita	1.866	2.948	66.97	0.571	2.67
Senecio spathulatus^{R}	1.858	2.935	69.91	0	2.33
Hydrocotyle hirta	1.802	2.847	72.75	0.143	2.67
Mitrasacme polymorpha	1.732	2.736	75.49	0.286	1.78
Themeda triandra	1.546	2.441	77.93	16	14.2
Cassytha filiformis	1.261	1.992	79.92	0	1.22
Cynodon dactylon	1.123	1.774	81.7	0.143	1.67
Lagenophora stipitata	1.009	1.594	83.29	0	1.33
Lobelia purpurascens	0.9793	1.547	84.84	0.571	0.889
Entolasia stricta	0.8827	1.394	86.23	0	1.11
Gonocarpus hirtus	0.8086	1.277	87.51	0	1
*Lysimachia arvensis**	0.7025	1.11	88.62	0	1.11
Mitrasacme paludosa	0.6729	1.063	89.68	0	0.889
Lomandra multiflora	0.6537	1.033	90.71	0.143	0.556
Phyllanthus virgatus	0.6483	1.024	91.74	0	0.889
*Conyza bonariensis**	0.6121	0.9669	92.71	0	0.889
Podolobium scandens	0.5588	0.8827	93.59	0.714	0
Lachnagrostis filiformis	0.4728	0.7468	94.33	0	0.778
Zieria prostrata^{R}	0.4585	0.7243	95.06	0	0.444
Xerochrysum bracteatum	0.4206	0.6643	95.72	0	0.556
Parsonsia straminea	0.3439	0.5433	96.27	0	0.333
Isolepis cernua	0.3365	0.5315	96.8	0	0.444
Stackhousia viminea	0.3354	0.5299	97.33	0.286	0.222
Bacopa monnieri	0.2481	0.392	97.72	0.286	0
Casuarina glauca	0.2431	0.384	98.1	0	0.333
*Paspalum mandiocanum**	0.2375	0.3752	98.48	0.286	0
Desmodium varians	0.2215	0.3499	98.83	0	0.333
Tricoryne anceps	0.1994	0.3149	99.14	0	0.333
Brunonia australis	0.1621	0.256	99.4	0	0.222
Geitonoplesium cymosum	0.1146	0.1811	99.58	0	0.111
Pultenaea maritima^{R}	0.1146	0.1811	99.76	0	0.111
Ophioglossum lusitanicum	0.08411	0.1329	99.9	0	0.111
*Paronychia brasiliana**	0.06645	0.105	100	0	0.111

While our results clearly suggest an advantage for floristic diversity from macropod grazing, even at high impact, this should not be equated with other forms of grazing (for example non-native herbivores) without research on impacts. We have not investigated the impacts on other elements of biodiversity such as fauna and faunal habitat requirements, or impacts on soil.

From the larger north coast NSW perspective however, high densities of macropods were only observed on a limited number of headlands (17%) with most headlands having either low or no observable macropods grazing (74%) (Table 1). Little grazed or ungrazed examples of grassy headlands were the norm. While ungrazed examples may contribute to structural (sward height) heterogeneity overall and may form floristically distinct (though species-poor) units, grazing by macropods may be beneficial on other headlands to maintain floristic diversity at all scales (alpha, beta and gamma).

We fully acknowledge the limitations of the current study which include a short observation period (4 years), and more importantly, that the experimental plots were only placed on a single headland. However, we believe the combination of our correlative comparisons, the highly significant results obtained from the single experiment, and the results matching those of other statistically significant correlational analyses within the same system and region (Hunter & Hunter 2017a), are worthy of consideration. Lack of replication across headlands means that it is unclear whether the strength of our results can be readily applicable to all *Themeda*-dominated headlands though we believe the results provide strong incentive for more extensive experimentation. Our results also indicate that high density grazing pressure from macropods may not be universally detrimental to the maintenance of floristic diversity in some grass dominated vegetation types.

Conclusion

Exclusion of macropod grazing pressure over four years was associated with significant and sustained losses of species diversity, relative abundance and lowered species colonisation leading to homogenisation and a distinct but species-poor flora. In agreement with other studies on NSW coastal headlands, macropod grazing, even at high densities and impact, were associated with higher floristic species diversity (alpha, beta and gamma), threatened flora occurrence and individual plant numbers without a notable reduction in the dominance of *Themeda triandra*. High intensity macropods grazing was not associated with degradation or loss of the endangered floristic community or threatened flora species within it but was found to be associated with an increased occurrence of introduced species. In spite of a lack of replication across other headlands the strength of the results and agreement with recent studies would suggest that macropod grazing may be an important feature that helps maintain floristic species diversity within plots, between plots and at the headland scale in *Themeda*-dominated communities on headlands and seacliffs within the North Coast Bioregion of New South Wales.

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The coastal ferns *Asplenium decurrens* and *Asplenium difforme* (Aspleniaceae) on the south coast of New South Wales.

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***Abstract*:** The occurrence of the coastal ferns *Asplenium decurrens* and *Asplenium difforme* (family Aspleniaceae) on the south coast of New South Wales are assessed and discussed. The Illawarra coast was the zone of overlap for these two coastal fern species and they reached their geographical limits in the Kiama area, with *Asplenium decurrens* reaching its northern limit of distribution and *Asplenium difforme* reaching its southern limit. All substantiated records of these ferns are documented and assessed.

Both species require conservation consideration on the NSW south coast. For *Asplenium decurrens* the evidence suggests that New South Wales should follow Victoria and list this species as threatened under the *Biodiversity Conservation Act 2016* (NSW). For *Asplenium difforme* local conservation action is needed at its most southern limit at Kiama.

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Introduction

The coastal ferns *Asplenium decurrens* (syn. *Asplenium obtusatum* subsp. *northlandicum*) and *Asplenium difforme* (syn. *Asplenium obtusatum* var. *difforme*) are very rare on the south coast of New South Wales, both having only ever been recorded at a handful of locations. All known records of these species on the south coast are here documented and assessed. A recent discovery has confirmed the most southern known location of *Asplenium difforme* at Kiama after a gap of 48 years and where it was first collected 132 years ago. The historic northern most limit of occurrence of *Asplenium decurrens* was Shellharbour, based on a collection in the late 1880s; Bowen Island at Jervis Bay is the current known northern limit of this fern. Thus, the Illawarra coast was the zone of overlap for these two coastal fern species.

These terrestrial ferns are similar in habit and their habitat preference and are clearly closely related. Each produces a short rhizome and rather thick fronds, growing to about 30 cm tall. The majority of the plants of *Asplenium difforme* at Kiama are small individuals. Clumps may form over time, although whether these are individual or clonal plants is unknown; see Figure 1. The habitat is amongst rocks close the sea, mostly within the influence of sea spray during high seas. Shady crevices appear to be preferred, probably where there is freshwater seepage from above, at least occasionally. Both species have thick fronds, an adaptation against desiccation in the harsh coastal conditions. Jones and Clemesha (1977) also note other adaptations to the harsh conditions of the coastal habitat, namely reduced stomata and a capacity for water storage in the fronds and rhizome.

As the species are spread by wind-borne spores, it could be expected that the species would not be limited in their ability to disperse and colonise more of the south coast. Their rarity across the region may be due to the fact that both are at their limit of distribution and therefore have a tenuous existence in this region.

The species *Asplenium difforme* also occurs on Norfolk Island, where it is quite common on coastal rocks. The species does not occur far inland on this island, where presumed hybrids with the local endemic species *Asplenium dimorphum* occasionally occur (K. Mills pers. obs.). Hybridisation has also been reported between *Asplenium decurrens* (as *Asplenium obtusatum*) and *Asplenium australasicum* on Montague Island (Heyligers. & Adams 2004) and hybrids with *Asplenium flaccidum* and with *Asplenium bulbiferum* have been reported (Flora of Victoria online).

Taxonomy

There has been considerable confusion over the naming of these species in the past, with few currently available publications in agreement regarding their taxonomic status. Originally named *Asplenium decurrens* Willd. (Willdenow 1810), this taxon was later named *Asplenium obtusatum* G. Forst. subsp. *northlandicum* Brownsey (Brownsey 1977). More recently, Shepherd *et al*. (2008), including Brownsey as a co-author, re-instated the original name *Asplenium decurrens* Willd.; Brownsey & Perrie (2016) set out the reasoning for re-instating the original name.

The Flora of New Zealand (online) summarises the situation regarding *Asplenium decurrens*: "*Asplenium obtusatum* was previously considered to include both subsp. *obtusatum* and subsp. *northlandicum* (Brownsey 1977). However, Shepherd *et al.* (2008) showed that *Asplenium decurrens* (as *A. northlandicum*) is an allopolyploid species, with either *Asplenium obtusatum* or *Asplenium oblongifolium* as the chloroplast parent and an unknown tetraploid as the other parent. Their conclusion supported the recognition of *Asplenium decurrens* as a distinct octoploid species, rather than a subspecies of the tetraploid *Asplenium obtusatum*." The name *Asplenium decurrens* is used here as it is a validly published name (Brownsey & Perrie 2016) for the octoploid, which is accepted as distinct from the tetraploid *A. obtusatum. Asplenium decurrens* has recently been added to the NSW Herbarium online flora PlantNet.

The closely related taxon *Asplenium difforme* R. Br. has been known as *Asplenium marinum* L. var. *difforme* F.M.Bailey and as a variety of the above taxon, namely *Asplenium obtusatum* G. Forst. var. *difforme* (R.Br.) Hook. The name *Asplenium difforme* was reinstated by Brownsey (1998) and the name is accepted in Australian Plant Census.

Asplenium decurrens

This fern is known as Shore Spleenwort and is very rare in New South Wales. The species is common around Tasmania, the North Island of New Zealand and the Kermadec Islands. It is occasional in Victoria and Western Australia where it is listed as threatened in both states. The species is very scattered along the Victorian coast and is said to favour granite outcrops (Wakefield 1975; Duncan & Isaac 1986; Flora of Victoria online). In Tasmania, the species is common around the shores of that island and the smaller islands to the north (Garrett 1996).

There are 21 confirmed records from seven locations along the NSW south coast (date range 1884 to 2018), stretching from Shellharbour and Kiama in the north to the Victorian border in the south; see Appendix 1. Twelve of these records are from two islands, namely Bowen Island and Montague Island. Most records come from south of Montague Island, with only three substantiated locations north of Montague Island. Heyligers and Adams (2004) state that *Asplenium decurrens*, as *Asplenium obtusatum*, is "frequently found among the rocks along the east side of the island" and it is "common in crevices between, and sheltered by, taller rock outcrops around the periphery of the island." This may be the largest population of this species in New South Wales.

The most northern record is Shellharbour (one collection in 1884), where it is almost certainly extinct; the 1884 record was probably on the sea cliffs at Barrack Point. The other northern locations are Kiama and Bowen Island. The collections from the Kiama area are historic, made in 1884, 1886 and 1894 (see Appendix 1). There are reports to the north of Shellharbour, extending to the northern tablelands, but except for one collection (near Sydney), the records are not supported by specimens and are considered to be dubious identifications, particularly those at high inland altitudes. The collection labelled as this species in the Janet Cosh Herbarium at The University of Wollongong is not this species; the specimen is re-determined as *Deparia petersenii* subsp. *congrua* (Woodsiaceae) (K. Mills, May 2019), a species with similar linear sori; this taxon was once placed in *Asplenium*.

The presence of *Asplenium decurrens* on Bowen Island, part of the Commonwealth Jervis Bay Territory, has recently been confirmed (D. Maple, Booderee National Park, pers. comm., 2018). A photograph of the species from that island appears below (Figure 1). Bowen Island seems to be the current northern limit of the species; the author's much searching of the rocky coasts to the north over several years failed to find the species.

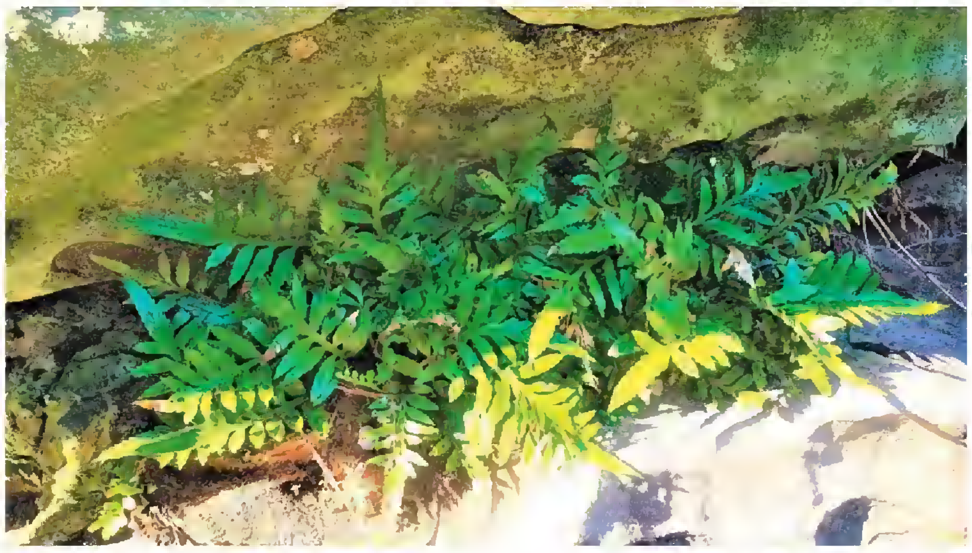

Fig. 1. The healthy colony of *Asplenium decurrens* on Bowen Island, Booderee National Park, Jervis Bay.

Photograph compliments of Dion Maple, Booderee National Park. (April 2018)

Asplenium difforme

The coastal *Asplenium* species north of Sydney is *Asplenium difforme*, which is said to occur as far south as the Sydney suburb of La Perouse (e.g. Benson & McDougall 1993). The southern limit of *Asplenium difforme* is however Kiama, as confirmed by specimens and recent observations by the author (see Appendix 1 and below). The species are differentiated by the thicker, fleshier fronds of *Asplenium decurrens* that are never more than pinnately divided compared to the more dissected fronds of *Asplenium difforme*; (see Figures 1, 3). This species occurs along the north coast of NSW, in the southeast corner of Queensland and on Norfolk Island.

Prior to the author's re-discovery of the species at Kiama, the most recent record from that area was a specimen collected by Clemesha and Lundie in 1971; see Appendix 1. A recent discovery of four small plants and one clump of plants in the Kiama area is therefore the first from that locality for 48 years. The plants were found in rock crevices just above the upper splash zone on a south-facing cliff directly above the sea; (see Figures 2, 3, 4). The plants are growing with typical local coastal plants, namely *Samolus repens*, *Cyrtomium falcatum** and *Coprosma repens**. Searching of the sea cliffs from Barrack Point (Shellharbour) southwards along the Shellharbour - Kiama coast to Seven Mile Beach in 2017-2019 failed to find either *Asplenium* species. For conservation reasons, the exact location of the plants at Kiama is not specified.

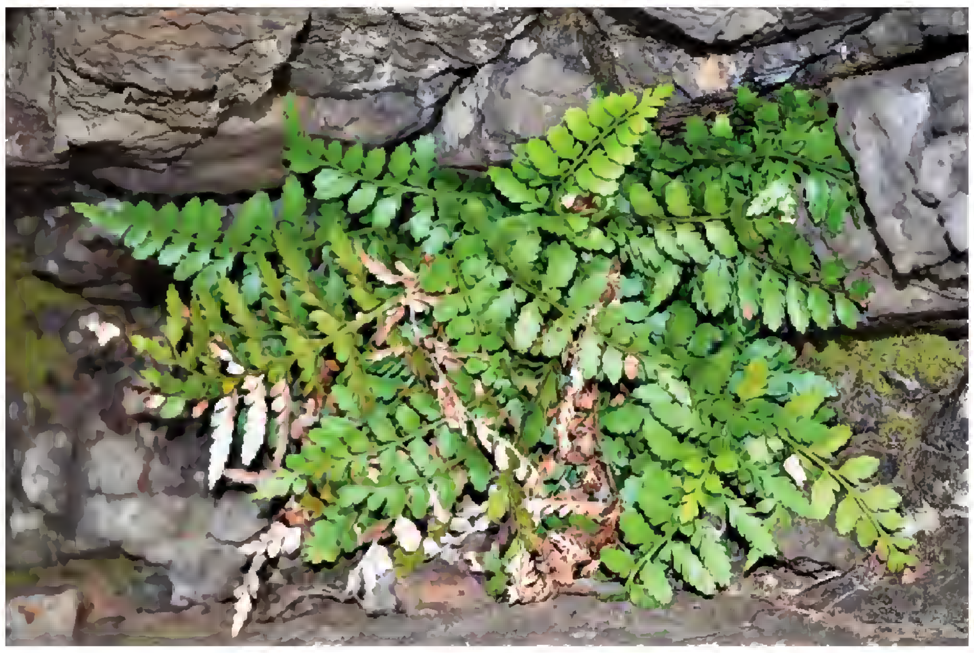

Fig. 2. *Asplenium difforme* growing at Kiama; whether these are individual or clonal plants is unknown. (January 2019)

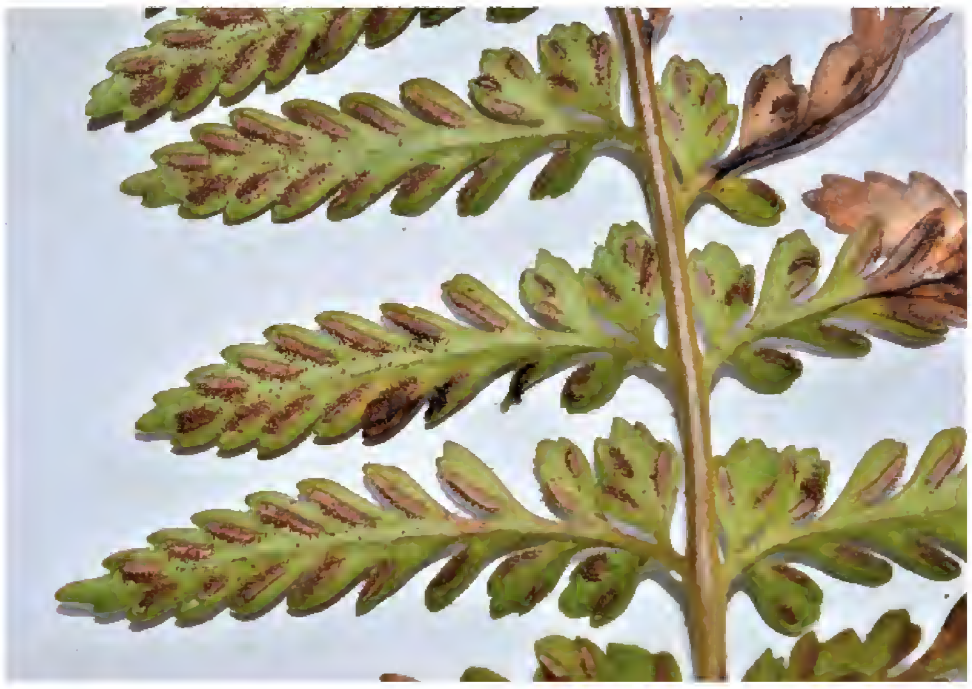

Fig. 3. Underside of a fertile frond of *Asplenium difforme* found at Kiama. (January 2019)

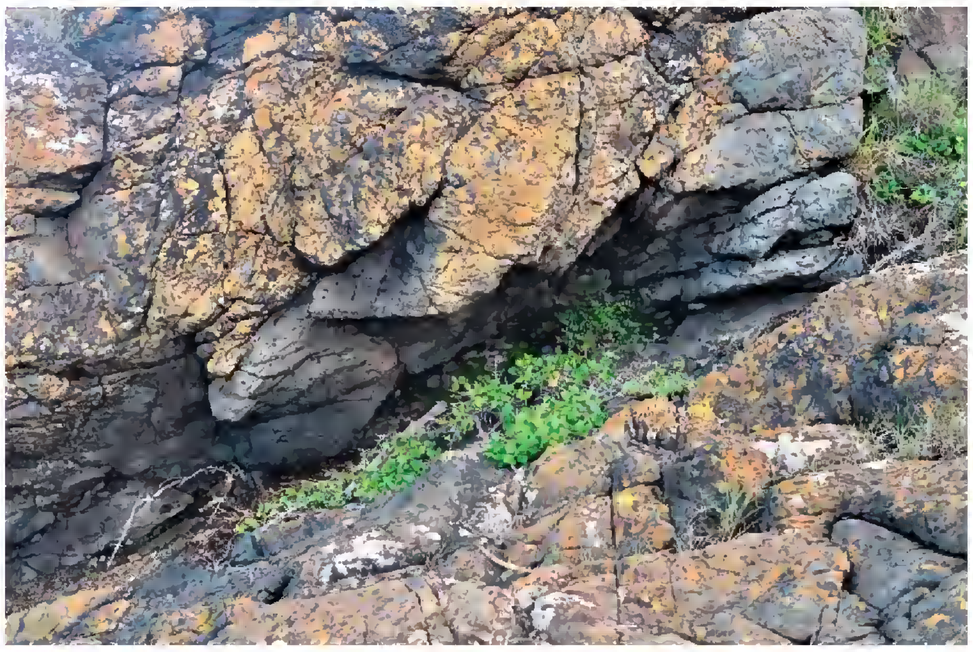

Fig. 4. Habitat of *Asplenium difforme* at Kiama. (March 2019)

A clump of ferns can be seen at the back of the crevice.

Conservation

The coastal fern *Asplenium decurrens* is very rare in New South Wales and indeed on the Australian mainland, as it is also rare in Victoria. In NSW the species is restricted to the south coast, where it has only ever been found at seven locations; there have only been six records from three locations since 1985. The evidence suggests that New South Wales should follow Victoria and list this species as threatened under the *Biodiversity Conservation Act 2016* (NSW).

While not threatened in NSW, *Asplenium difforme* requires conservation action at its most southern limit at Kiama where weeds threaten its existence at this site. Kiama Municipal Council manages the public land where the species occurs, and would be the most appropriate authority to take the necessary actions to protect the plants.

Acknowledgements

The National Herbarium of NSW, Sydney is thanked for providing access to the Herbarium collections. Daniel Ohlsen of the National Herbarium of Victoria, Melbourne, kindly checked the specimens in that institution and provided relevant information. Matt Renner and the Editorial Committee provided comments on the manuscript.

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Appendix 1

Records of *Asplenium decurrens* and *Asplenium difforme* in southern NSW

Location[1]	**Date**	**Record**
Asplenium decurrens		
NC (no specimens)		
SW Solitary Island[2]	28/04/1974	‘default sighting’
NT (no specimens)		
Mt Boonangai area[3]	01/03/2000	vegetation survey
	02/03/2000	vegetation survey
	21/03/2000	vegetation survey
CC (no specimens)		
Fern Tree Creek, Metropolitan Special Areas Water Catchment west of Wollongong[3]	2003-2009	vegetation surveys
SC		
Shellharbour	01/02/1884	specimen MEL114924, S.W.Cocks
Kiama	01/02/1884	specimen MEL114940, S.W.Cocks
Kiama	08/1886	specimen NSW195441, WB (Bauerlen)
Kiama	1894	specimen MEL114870, S.W..Cocks
Bowen Island	01/10/1922	specimen NSW195443, F.A.Rodway
Unknown (likely Bowen Island)	19/10/1933	specimen NSW, F.A.Rodway
Bowen Island	18/09/1996	specimen NSW500598, N.M.Taws
Bowen Island	18/09/1996	specimen MEL2276753, N.M.Taws
Bowen Island	18/09/1996	specimen CBG9914365, N.M.Taws
Bowen Island	04/04/2018	photographs, D. Maple
Montague Island	01/06/1921	specimen NSW195444, W.H.Williams
Montague Island	01/02/1933	specimen NSW738847, L.R.Fraser
Montague Island	26/02/1935	specimen NSW195440, A.Melvaine
Montague Island	07/08/1964	specimen NSW195445, J.Cassell
Montague Island	30/03/1994	specimen, CBG465918.1, P.C.Heyligers
Montague Island	30/03/2000	specimen NSW623427, P.C.Heyligers
Eden	1880	specimen, MEL114941, E.Reader
Green Cape	01/12/1920	specimen NSW195446, F. A. Rodway
Green Cape	10/10/1954	specimen NSW481133, F. Constable
Nadgee NR	22/11/1982	specimen, CBG8403506.1, P.Gilmore
Nadgee NR	21/01/1985	specimen, MEL675838, D.E.Albrecht
Asplenium difforme		
CC		
Shellharbour	01/02/1884	specimen MEL0114924A, W.Cocks
Kiama	1894	specimen MEL114605A, W.Cocks
Kiama	1970	specimen CBG8408180.0, B.Whitehead
Kiama	01/05/1971	specimen MEL294719, S.Clemesha
Kiama	04/06/2018	specimen, photographs, K.Mills,
Kiama	20/01/2019	specimen, photographs, K.Mills,

1. Botanical subdivisions: NC - north coast; NT - northern tablelands; CC - central coast; SC - south coast.
2. This observation is almost certainly *Asplenium difforme*.
3. These sites are well inland and mostly at high altitude and very unlikely to contain this coastal species. The records are not substantiated by specimen.

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Growth of ornamental palms, *Phoenix* and *Washingtonia*, as epiphytes on suburban street trees in Albury, NSW, Australia

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Abstract: Palms are ubiquitous as landscaping plants in many urban areas. Dispersed by frugivorous birds and often tolerated as self-seeded plants by the property owners, *Phoenix canariensis (*Canary Islands date palms) and two species of fan palms (*Washingtonia robusta and Washingtonia filifera*) in particular, have become established in many urban spaces. This paper examines the establishment of such self-seeded palms as epiphytic growth in crooks and branch scars of suburban street trees. Given the limited nutrient availability and the restricted space for rootmass development, these palms undergo a natural bonsai process. Some palms have persisted for over a decade without reaching sexual maturity. While the epiphytic growth demonstrates the palms' further dispersal capability, it does not appear to increase their potential invasiveness into new areas of land.

Keywords: *Phoenix canariensis, Washingtonia robusta*, dispersal, marginal environments, frugivory

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Introduction

Phoenix canariensis Chabaud (Canary Islands date palms) and *Washingtonia robusta* Wendland (Mexican fan palms) are ubiquitous ornamental plants which were distributed by the horticultural industry during the late nineteenth and early twentieth centuries (Bailey, 1936, p. 63ff; Ishihata & Murata, 1971; Spennemann, 2018a, 2019b; Zona, 2008) well beyond their endemic ranges in the Canary Islands (Naranjo, Sosa, & Márquez, 2009) and northern Mexico respectively (Cornett, 1989; McCurrach, 1960, p. 264f). Both have become major ornamental trees on a global scale, planted in private and public gardens, as well as on occasion, as street trees in many communities with a temperate climate (Spennemann, 2018c).

Phoenix canariensis is a dioecious anemophilous plant which typically grows to a height of 18–20 m, with a trunk diameter between 0.6 and 1.2 m. The crown tends to reach a diameter of 10-12m, made up of in excess of 200 arching, pinnate leaves of 5-6m (max 7m) length. The abscission scars of the fronds are rhomboid, giving the stem a characteristic appearance. *Phoenix canariensis* reaches reproductive maturity and first flowers after six to seven years (in some locales between 8 to 10 years). The date palm readily and reliably sets fruit and seeds freely, annually producing between 5,000 and 30,000 obovoid drupes ('dates') which vary widely in their physical properties (shape, length, diameter, mass, colour) between individual palms (Djouab et al., 2016; Saro, Robledo-Arnuncio, González-Pérez, & Sosa, 2014). The drupes range from 15-30 mm in length, 12-17 mm in thickness and 2–5 g in mass (Djouab et al., 2016), of which the seed contributes less than 0.9–1.5 g. The seed requires germination temperatures of between 25ºC and 35ºC (Chatty & Tissaoui, 1999) and germinates under natural conditions after 83-110 days. It shows its first two-leave shoots at about one year of age.

Washingtonia robusta is a monoecious, self-compatible plant which typically grows to a height of 15 to 20 m with a trunk diameter of 0.6 to 1.2 m. The palm can have in excess of 30 bright green, costapalmate fronds of 0.9 to 1.8 m with two-cleft divisions, which are attached to the tree with a 1.2–1.5 m long plano-convex petiole which exhibits curved spines on its entire length. The palms reach maturity after they have reached at least 3m in height. *Washingtonia robusta* seeds freely, annually producing between 100,000 and 300,000 globular drupes. The drupes range from 7-10mm in length and 6–8 mm in thickness with an average weight of 0.25g. The seeds germinate well within 14 days at ideal soil temperatures of 25-35ºC (summarised in Spennemann, 2018b).

In the Australasian setting, *Phoenix canariensis* has been formally regarded as naturalised in New South Wales (Hosking, Conn, Lepschi, & Barker, 2007), South Australia (Brodie & Reynolds, 2012), south-eastern Queensland (Biosecurity Queensland, 2018), Victoria (Conn & Walsh, 1993), and Western Australia (Lohr & Keighery, 2016, p. 32), as well as Norfolk Island (Biosecurity Queensland, 2018) and New Zealand (Esler, 1987). *Washingtonia robusta* is regarded as naturalised in parts of Western Australia (Keighery, 2010), New South Wales (Spennemann, 2018e) and the North Island of New Zealand (Martin, 2009).

Both *Phoenix canariensis* and *Washingtonia robusta* are adventitious species. As garden escapees *Phoenix canariensis* have become an invasive environmental plant in a number of countries, even though the exact biomechanical and biochemical processes of dispersal are not yet well understood (Spennemann, 2019c). Likewise, *Washingtonia robusta* can establish, at least temporarily, even in rather marginal places (Martin, 2009; Spennemann, 2018e; Stein, 2010). The long-term success of these occurrences is dependent on stable availability of nutrients as well as a lack of human intervention. Both plants provide significant ecological provisioning services in modified urban/peri-urban habitats and emergent novel ecosystems (Spennemann, 2019d).

While there are numerous papers that discuss epiphytic growth of ferns and other plants *on* Canary Islands date palms (Brandes, 2001, 2007; Labbe, 1953; Maire, 1942; Morici, 1998; Richter, 1985; Riefner, 2016; Zubčić, 2017), there are no papers that formally describe epiphytic growth *of* Canary Islands date palms or *Washingtonia* palms on other plants. The author observed and described a *Washingtonia robusta* growing in a branch scar of a London plane tree (*Platanus x acerifolia*) in Albury (Spennemann, 2018g). Subsequently, other occurrences have been noted (described in this paper).

This paper is the first formal discussion of *Phoenix canariensis* and *Washingtonia robusta* palms growing epiphytically on large ornamental trees in public park and streetscape settings.

Methods

Albury is a rural service centre in southwestern NSW with an average annual rainfall of 700 mm and average seasonal temperatures of 2.7°C in winter and 31.2°C in summer. Central Albury is dominated by streets lined with mature trees and well established residential gardens, many of which contain exotic palms (primarily *Phoenix canariensis* and *Washingtonia robusta*). The street trees are all deciduous species, primarily comprised of elm (*Ulmus glabra*), London plane trees (*Platanus x acerifolia*), Red Canadian Maple (*Acer rubrum*), and Green Ash (*Fraxinus pennsylvanica*). Residual Eucalypts only exist peripheral to the urban core, confined to suburb developments post-dating the early 1930s.

All street trees of central Albury were systematically surveyed for the presence of palms growing in the crooks or branch scars. The survey was focussed on residential streets with established street tree plantings. In the first instance, the survey was carried out by vehicle to establish the presence of established large trees. These were then inspected on foot. The survey was carried out in July and August 2019, during the southern winter, when the trees had lost their foliage. This ensured that the trees were observable in their entirety.

Those trees with epiphytic growth of ornamental palms were photographically documented from all angles to be able to assess the growth habit of the juvenile plants and to count the number of their leaves (Spennemann, 2019e, 2019f, 2019g). In an attempt at establishing the age of the juvenile plants, all available Google Street View imagery was examined.

The time depth for the age assessment varies as the spatial coverage was limited to the main roads at the beginning of the service. The initial coverage by Google in November 2007 also used lower resolution cameras and greater photo intervals.

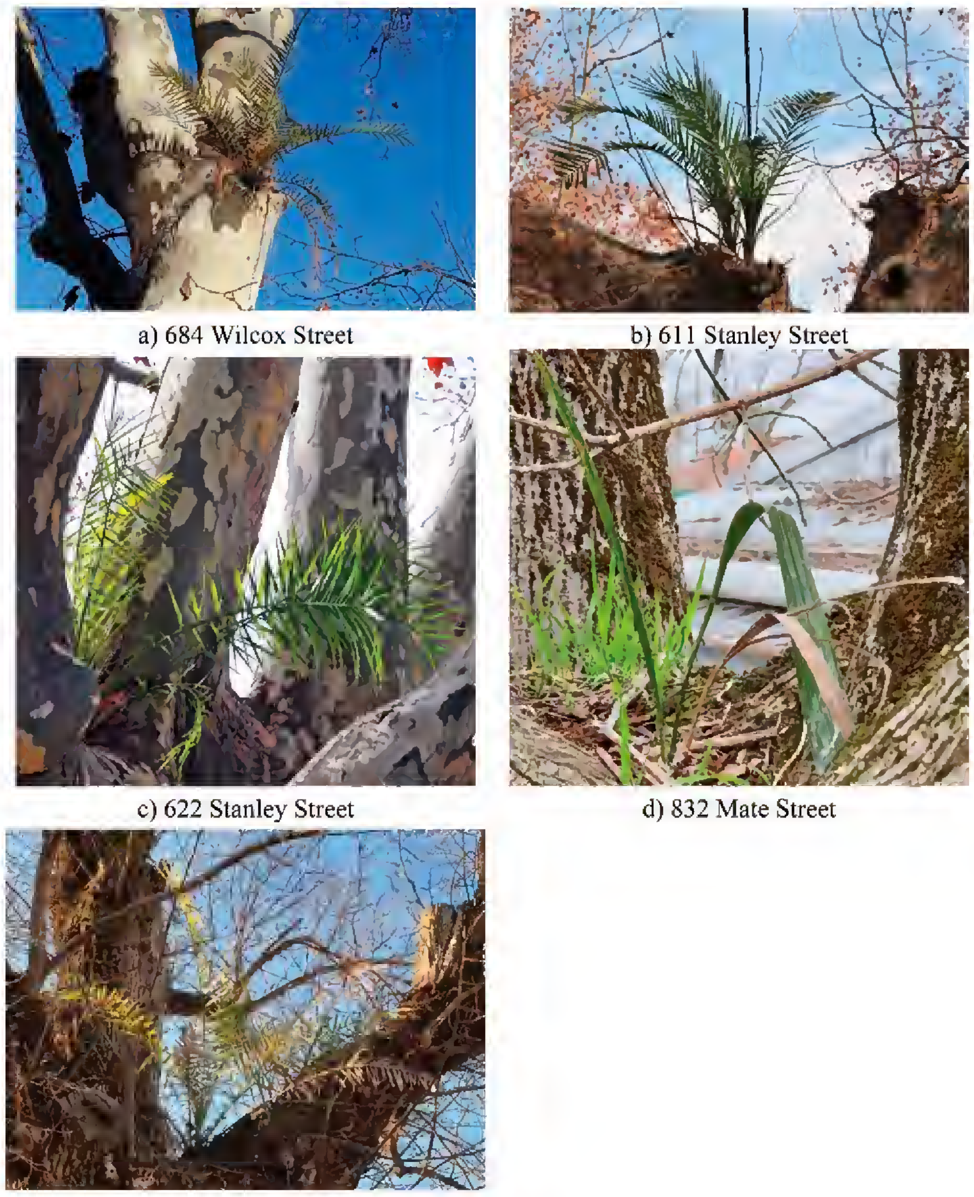
a) 684 Wilcox Street
b) 611 Stanley Street
c) 622 Stanley Street
d) 832 Mate Street
e) 782 David Street

Fig. 1. Examples of *Phoenix canariensis* growing on London plane trees (a–c) and elms (d–e) in Albury.

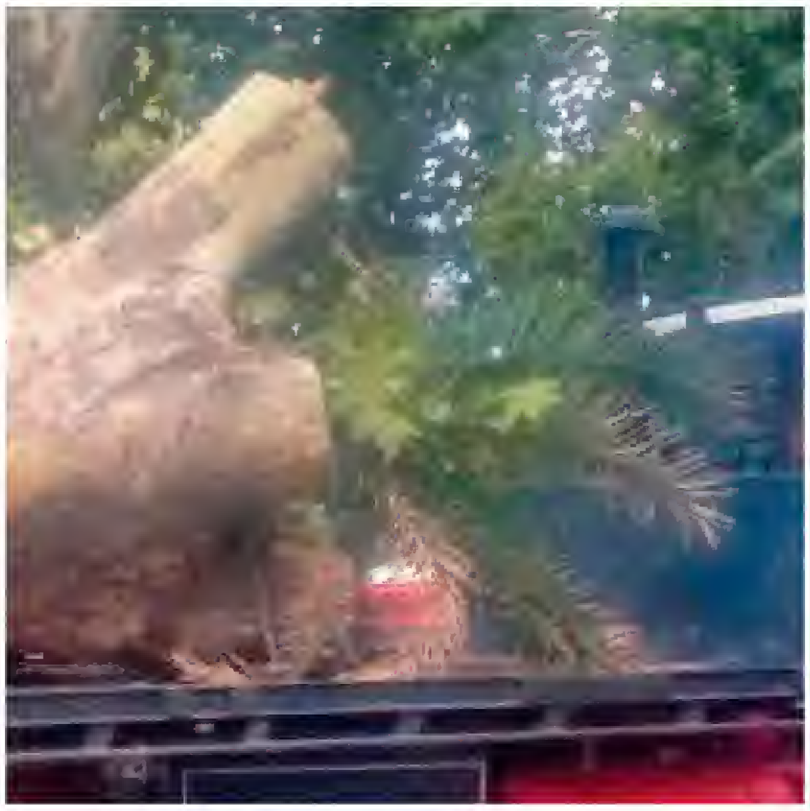

Fig. 2. A felled London plane tree at Noreuil Park, Albury with a *Phoenix canariensis* emerging from the crook of the tree.

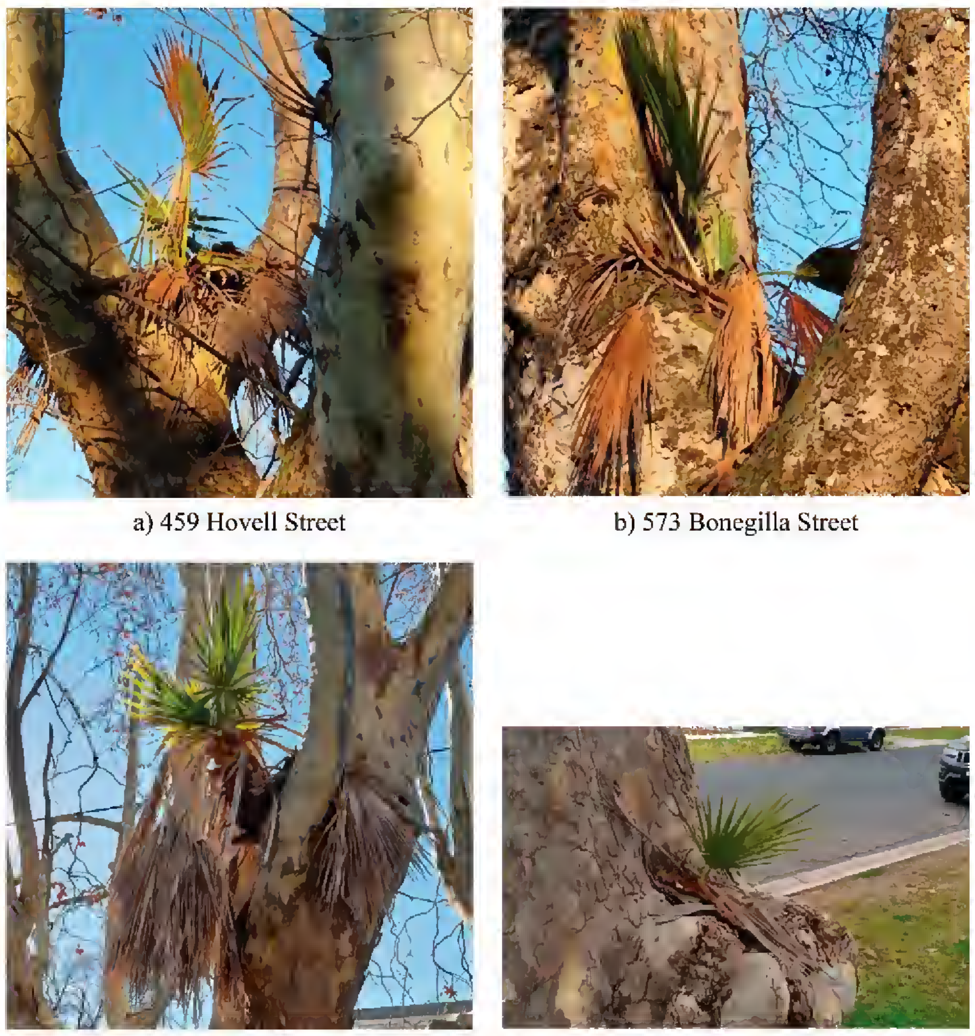
a) 459 Hovell Street
b) 573 Bonegilla Street
c) 577 Macauley Street
d) 641 Macauley Street

Fig. 3. Examples of *Washingtonia robusta* growing on London plane trees (a–d) in Albury.

Results

The survey encountered six juvenile *Washingtonia robusta* plants (at five locations) and four *Phoenix canariensis* plants (at three locations) growing in London plane trees (Table 1 nº 1–4, 10–13) and two *Phoenix canariensis* growing on *Ulmus glabra* (Table 1, nº 8-9). An additional *Phoenix canariensis* once existed at Noreuil Park (Table 1 nº 7), but the London plane tree had been removed during park development in April 2019. Four additional *Phoenix canariensis* were noted outside the survey area, two on *Ulmus glabra* and two on *Platanus x acerifolia* (Table 1 nº 5–6, 8–9) (for photographic documentation, see Spennemann, 2018g, 2019e, 2019f, 2019g). Although, the survey encountered no examples of dead juvenile specimens, it is possible that small dead seedlings may have been overlooked in London plane trees (i.e. interpreted as background leaf matter).

The size of the plants, their growth habit, as well as their approximate ages are set out in Table 1. The ages of the plants are all minimum ages. They are based on the time elapsed since the historic Google Street View image that shows their pinnate leaves, with an additional year added for emergence and formation of the two-leaf seedling.

Table 1. Instances of epiphytic growth of ornamental palms in Albury, NSW (July-August 2019)

					Size	Leaves		Age	Image
Nº	Location	Host Tree	plant	Habit	(cm)	green	brown	(yr)	
			Phoenix canariensis						
1	684 Wilcox St	Platanus x acerifolia		juvenile	0.8–1.0	9	7	> 11	Fig. 1a
2	611 Stanley St	Platanus x acerifolia	South	juvenile	0.5–0.6	5	—	> 5	Fig. 1b
3	611 Stanley St	Platanus x acerifolia	North	juvenile	0.5–0.6	5	—	> 5	Fig. 1b
4	622 Stanley St	Platanus x acerifolia		juvenile	0.7–0.9	7	—	< 5	Fig. 1c
5	370 Tribune St	Platanus x acerifolia	South	juvenile	0.6–0.7	4	—	> 3	Fig. 4a
6	370 Tribune St	Platanus x acerifolia	North	juvenile	0.6–0.7	5	1	> 3	Fig. 4a
7	Noreuil Park	Platanus x acerifolia		juvenile	1.1–1.4	?6–8	?4–6	> 3	Fig. 2
8	832 Mate St	Ulmus glabra		seedling	0.3–0.4	2	1	< 2	Fig. 1d
9	782 David St	Ulmus glabra		juvenile	0.7–0.9	8	7	> 3	Fig. 1e
			Washingtonia robusta						
10	459 Hovell St	Platanus x acerifolia	South	juvenile	0.8–1.0	3	6	> 5	Fig. 3a
11	459 Hovell St	Platanus x acerifolia	North	juvenile	0.3–0.5	2	6	> 5	Fig. 3a
12	573 Bonegilla St	Platanus x acerifolia		juvenile	0.6–0.8	3	7	> 5	Fig. 3b
13	641 Macauley St	Platanus x acerifolia		juvenile	0.3–0.4	3	5	> 2	Fig. 3d
14	568 Macauley St	Platanus x acerifolia		juvenile	0.4–0.5	3	5	≤ 3	Fig. 4b
15	577 Macauley St	Platanus x acerifolia		juvenile	1.2–1.3	3`	45+	> 11	Fig. 3c

Discussion

The height above ground of the crook or branch scar in which the juveniles are growing is determined by the height of pollarding and/or the required clearance for overhead powerlines and thus incidental to the plant's establishment. In all instances, the seeds would have been deposited by a volant vector. The street trees in which *Phoenix canariensis* and *Washingtonia robusta* juveniles are growing are all within 300 m of the closest fruit-bearing palm, and thus in easy flight range for many bird species.

A global review of the vectors responsible for the dispersal of *Phoenix canariensis* (Spennemann, 2019c) and the two *Washingtonia* species (unpublished data) has shown that in the Australian case Pied Currawong (*Strepera graculina*), Starlings (*Sturnus vulgaris*) and Eurasian Blackbirds (*Turdus merula*) are the main vectors, followed by Australian Ravens (*Corvus coronoides),* Common Mynas (*Sturnus [Acridotheres] tristis)* and Blue-faced Honeyeaters (*Entomyzon cyanotis)*. While all species, except the Common Myna, are common in Albury, some are less likely to be dispersers due to their behaviour. An example is the Eurasian Blackbird which would take fruit to groundcover rather than carry it to an elevated perch.

The three instances of similar sized *Phoenix canariensis* juveniles growing in the same location (Fig. 1b, e; Fig. 3a) strongly suggests that each originates from a larger, multi-seed regurgitate of Pied Currawongs (see Spennemann, 2018d for appearance of such regurgitate.

Establishment

Both *Phoenix canariensis* and *Washingtonia robusta* readily establish in the managed garden environment of an urban community. Emerging seedlings and juveniles are commonly tolerated until they reach considerable size, by which time they are difficult to remove. *Washingtonia robusta* seems to have a slightly higher water requirement for successful establishment than *Phoenix canariensis*. Experiences in a non-artificially watered setting in the Southern Riverina have shown that *Phoenix canariensis* will readily establish, but that *Washingtonia robusta* will fail to do so (Spennemann, 2019a). If water is provided, such as in urban garden settings, the *Washingtonia robusta* can establish, at least temporarily, even in rather marginal places such as cracks in the pavements (Martin, 2009; Stein, 2010), concrete drains (pers. obs.), cavities in trees (this paper), or even in flooded wetlands (Spennemann, 2018e, 2018f). For both palms the long-term success of these colonisation attempts is dependent on a stable nutrient supply, as well as a lack of human intervention.

Overseas examples have shown *Washingtonia robusta* to successfully establish in *Pinus* species (San Diego [CA, USA] Nelson, 2019) and *Phoenix canariensis* to establish in *Ulmus* sp. (Auckland [NZ], Sullivan, 2001), *Metrosideros excelsa* (Auckland [NZ], Sullivan, 2015), (*Vitex lucens*) (Auckland [NZ], Sullivan, 2002) and *Fraxinus pennsylvanica* (Gisborne [NZ], Tutty, 2015).

Age of plants

The age structure of these epiphytic palms is difficult to assess. One *Phoenix canariensis* specimen is a seedling without pinnate leaf development, and thus between one and two years old (Table 1 nº 8), while another, based on Google Street imagery, is at least 11 years old (Table 1 nº 1). Several others are at least five years old, as are three of the *Washingtonia robusta.*

An epiphytic *Phoenix canariensis* specimen growing in the fork of a *Metrosideros excelsa* in Auckland has reached an age of at least five years (Sullivan, 2015), while a specimen growing in the fork of an *Ulmus* street tree in Auckland seems to have survived for at least 19 years, and probably considerably longer (Sullivan, 2001, ages verified via Google StreetView imagery).

Long-term prognosis

In many horticultural settings the size of the root ball, as constrained by the size of the planting container, will define the size of the plant. Palms are no exception. Data on container-grown palms for the horticultural trade show that the growth of palms will be inhibited and retarded when the root mass is confined by container size (Burch, Atilano, & Reinert, 1983; Meerow, 1994). Documented in the literature are extreme examples. For example, in 1905 the Philadelphia-based nursery Bell and Sons (1905b, 1905a) sold a thirty-five year old *Phoenix canariensis*, that had been kept potted through-out its life and only had attained a height of 2.4 m (with a crown of similar dimensions). Similarly, experiences with extreme pot size restrictions, as in the case of bonsaied palms (Calderón et al., 2019; Maidman, 2001), demonstrate the retardation of growth.

While the life expectancy of specimens grown in restricted pots tends to be reduced, with bonsaied palms lasting between four and ten years (Maidman, 2001), there is one *Washingtonia filifera* specimen on record which is twenty years old that has retained the appearance of a six-leaved juvenile (Calderón et al., 2019, p. 82). Likewise, the above cited examples from New Zealand suggest that epiphytic *Phoenix canariensis* can maintain their viability for prolonged periods.

In the Albury situation, all but two of the documented epiphytic palm specimens are growing in London plane trees, even though numerous maples and elm trees in particular exhibited broad forks and well structured, deep-fissure surfaces as well as branch cuts (following branch lopping due to overhead powerlines). Elms were observed to host a range of other epiphytic growth, in particular- mosses, grasses, sedges and occasional climbers. Common to all is that these plants require less soil substrate than palms.

Even where not required for clearance of over-head powerlines, London plane trees had been pollarded in the past for aesthetic reasons, giving rise to crooks and branch scars. A characteristic of the London plane trees is the rapid callus development that encircles the branch cut and grows in thickness and height. This results in a cup-like depression of varied depth, which traps leaf matter, and other plant debris and effectively acts like a shallow planting pot (Fig. 5). By and large, elm trees do not exhibit this characteristic. The substrate in which the palms are growing on the plane tree is primarily comprised of decaying bark and leaf matter, as well as fragments of seed balls of the host tree, with a small amount of wind-borne mineral dust (deposited during mid-summer wind gusts). While branch scars with raised callous rims are not suitable for collecting rainwater running off branches, palm leaves are shaped to maximise the collection of moisture and direct it via the petioles to the palm's growth point. Flowing rainwater also directs mineral nutrients (air borne dust) collected by the leaves to the growth point.

While both *Phoenix canariensis* and *Washingtonia robusta* are hardy plants once well established, that can survive periods of low moisture provision; the summers in Albury are hot and dry, causing considerable heat stress on plants. With one exception (which benefits from lawn watering - Table 1 nº 13), the palms in the plane trees obtain all their required moisture from direct precipitation and run-off down the palms' petioles and it can be speculated that moisture stress has not proved terminal because during summer the deciduous London plane trees exhibit a dense canopy with large leaves that produces continual dappled shade (Fig. 4). The evapotranspiration of the large-leaved plane tree or other densely-leaved tree both raises ambient moisture surrounding the palm and drops ambient temperature inside the canopy.

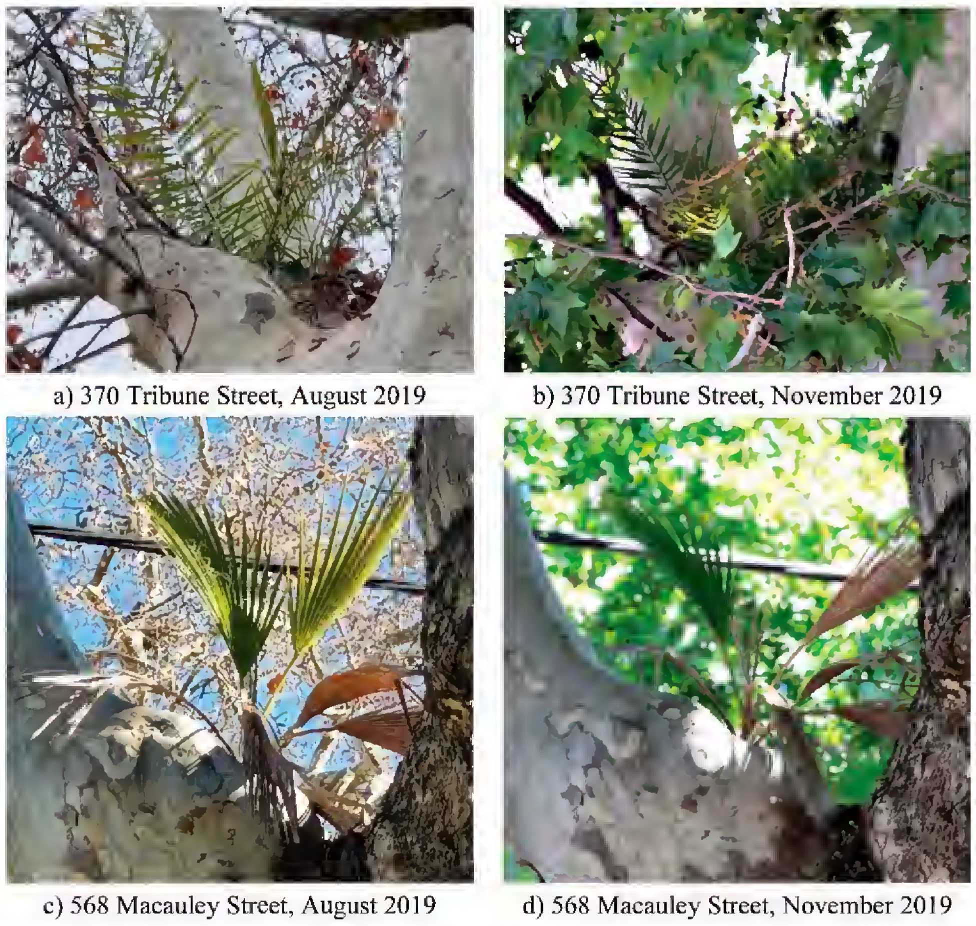
a) 370 Tribune Street, August 2019
b) 370 Tribune Street, November 2019
c) 568 Macauley Street, August 2019
d) 568 Macauley Street, November 2019

Fig. 4. Examples of *Phoenix canariensis* (a, b) and *Washingtonia robusta* (c, d) growing on London plane trees in Albury. Surrounding canopy cover in late winter (a, c) and early summer (b, d).

The growth rate, and short- to medium-term survival of epiphytic palm specimens is highly variable, as it is subject to the volume of the 'planting container,' *i.e.* the dimensions and in particular depth of the callous-ringed branch scar, as well as the amount of decayed leaf matter that had accumulated there before the deposition of the seed. The differential prevalence of palms on London plane trees is likely to be influenced by climatic conditions. The local climatic condition will have an impact on the survival of self-seeded epiphytic plants on different substrate species. Auckland, for example is more humid and has a higher precipitation rate than Albury, which implies that the bark and branch topography of a greater number of host tree species will provide the required moisture regime (Spennemann, 2019f).

The three observed instances of two specimens growing in the same branch scar (Fig. 1b, e, Fig. 3a) are not sustainable in the long term. In all instances, one of the two specimens is already marginally larger than the other. This differential will increase as the larger specimen will take a greater share of the nutrients, eventually leading to the death of its competitor.

The observation of the juvenile *Phoenix canariensis* in the felled London plane tree at Noreuil Park is very significant. Fig. 2 shows the felled and sawn-off tree trunk on the truck, with the palm still firmly rooted in the crook of the tree (presumably in a branch scar). This attests to the resilience of the palm as well as the strength of the root ball. It can be surmised that a palm could conceivably survive the collapse of a London plane tree and maintain growth, in particular if it were to come in contact with soil. In the well managed environment of urban street trees and public parks, however, this is a highly unlikely outcome.

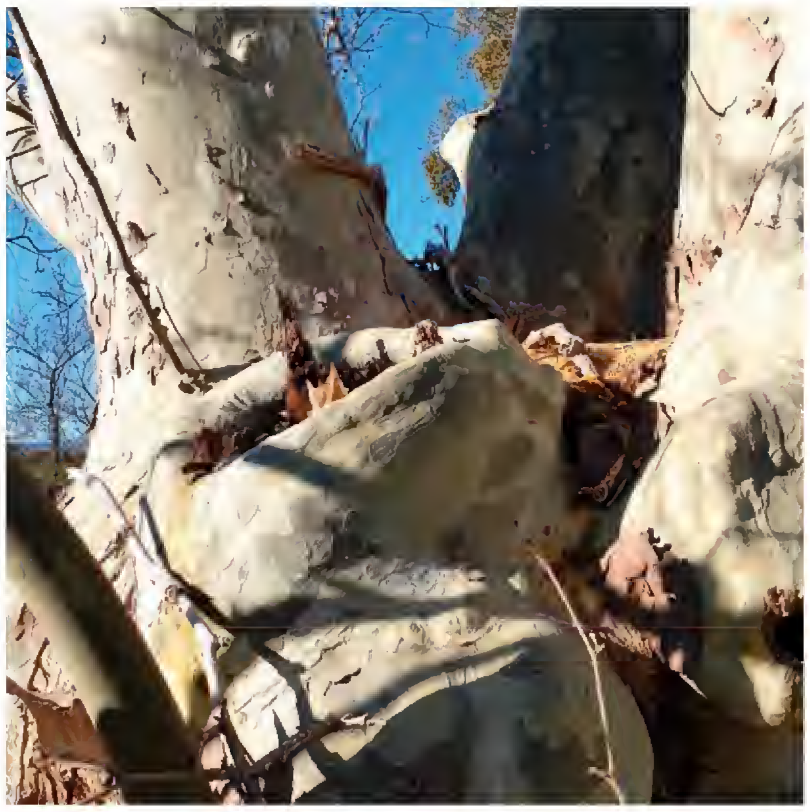

Fig. 5. A branch scar on a London plane tree showing callous growth resulting in a 'planting pot' situation. Note accumulated leaf matter as well as seeds.

Conclusion

For both palms *Phoenix canariensis* and *Washingtonia robusta* the plants studied so far, indicate the stunted growth and lack of adequate development appears to prevent them from reaching sexual maturity. Thus, from the plant's point of view, the successful germination and establishment of offspring as epiphytes in the branch scars of street and park trees demonstrates the plant's dispersal capability, but does not substantively do so in terms of its colonisation of new spaces.

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